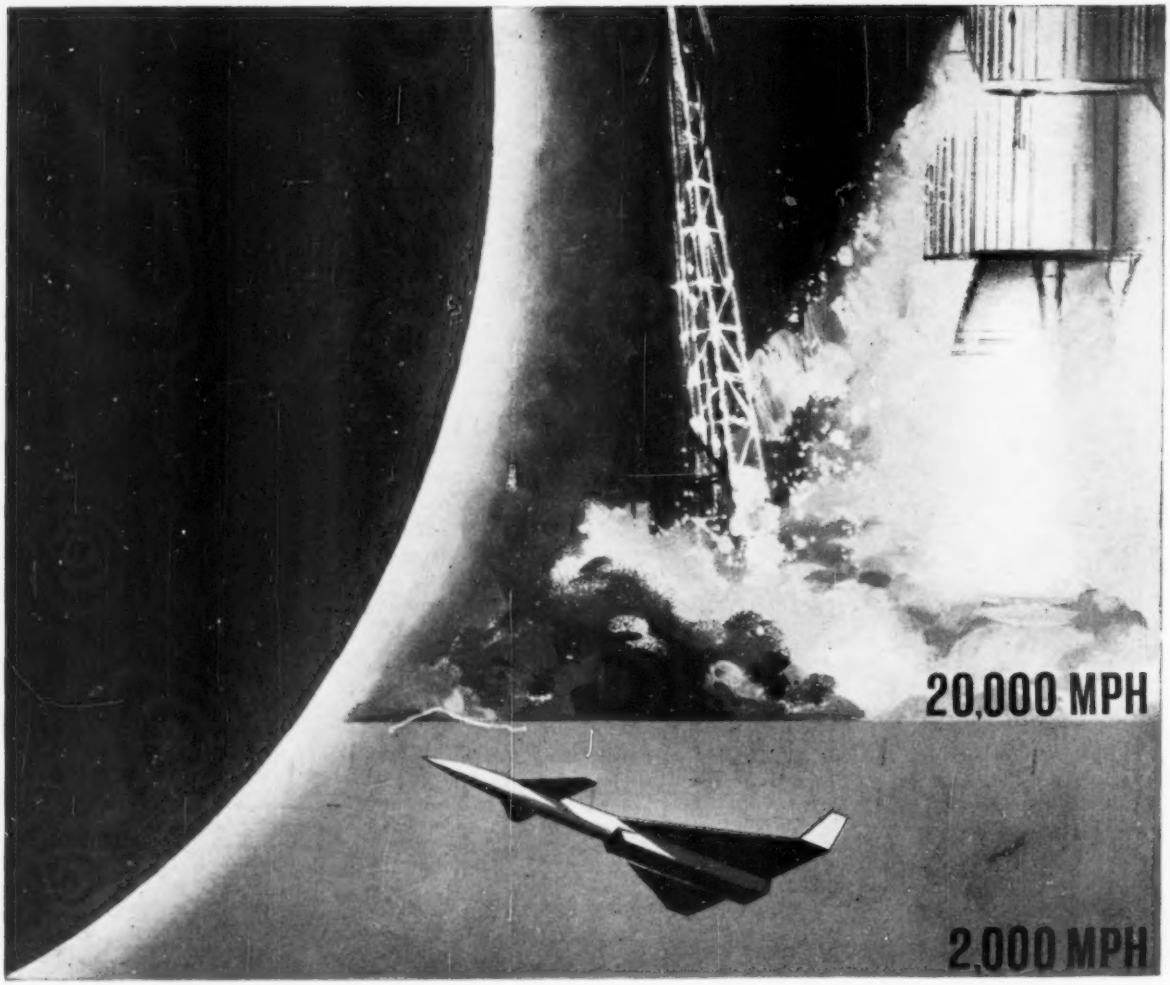
VOL. III No. 6

CONTENTS

NOVEMBER 1961

	Page
A TEN YEAR PROGRAMME OF SPACE TECHNOLOGY. L. R. Shepherd	190
LIQUID PROPELLENT MOTORS. W. N. Neat	193
ENGINEERING ASPECTS OF SOLID PROPELLENT MOTORS	198
HIGH-ENERGY CHEMICAL PROPELLENTS. F. Fitzgerald	199
WITH GAGARIN INTO ORBIT	204
SOME LEGAL PROBLEMS OF SPACE TRAVEL. J. M. Smail	206
UNCHANGING MOON? J. W. Macvey	210
A SUPER ECHO	212
SATURN LAUNCH COMPLEX 34	213
REVIEWS	217
CORRESPONDENCE	219



650 MPH

60 MPH

AEROSPACE - the new industry

Aerospace presents us with what is perhaps the most urgent industrialisation requirement of our time. Man-made satellites are required, virtually in quantity production, to operate as telecommunication relays and navigational aids. The development of the new techniques and materials is a familiar evolutionary process in the aircraft industry. It would be logical, therefore, to expect the aviation specialist to take the lead in this new and exciting venture.

HAWKER SIDDELEY AVIATION Kingston-upon-Thames, Surrey

SPACEFLIGHT

Volume III Nov. 1961 Number

THE MAGAZINE OF AEROSPACE SCIENCE AND TECHNOLOGY

Editor

KENNETH W. GATLAND, F.R.A.S.

Editorial Board

M. F. ALLWARD

C. A. CROSS, M.A., F.R.A.S.

D. HURDEN, B.A., GRAD. I. MECH. E.

A. E. SLATER, M.A., M.R.C.S., L.R.C.P., F.R.MET.S., F.Z.S.

Correspondence and manuscripts intended for publication should be addressed to the Editor at 42, Knightwood Crescent, New Malden, Surrey.

Opinions in signed articles are those of contributors, and do not necessarily reflect the views of the Editor, the Editorial Board or the Council of the British Interplanetary Society, unless such is expressly stated to be the case.

All material is protected by copyright. Responsibility for security clearance, where appropriate, rests with the author.

***Spaceflight* is published bi-monthly by the British Interplanetary Society, and is issued free to members.**

Full particulars of membership of the British Interplanetary Society may be obtained from the Secretary. The secretarial address is 12, Bessborough Gardens, London, S.W.1; telephone TATe Gallery 9371.

***Spaceflight* is distributed in North America by Sky Publishing Corporation, Harvard College Observatory, Cambridge 38, Mass., U.S.A. All enquiries concerning subscriptions and single copies should be sent to Sky Publishing Corporation.**

COVER

This model shows the appearance of Ranger III which embodies a television camera for close scrutiny of the Moon up to the moment of impact and an ejectable instrument capsule designed to "rough land" on the lunar surface. It will be launched from Cape Canaveral by an Atlas-Agena B.

Jet Propulsion Laboratory.

Year of the Astronauts

In his address before the Annual General Meeting of the B.I.S. on 15 September, Dr. W. R. Maxwell, the Society's President, remarked that astronautics was advancing so rapidly that there was scarcely time to assess the full significance of one step forward before another had taken place. This is particularly true of the progress which has been made this year in the field of manned spaceflight.

Hardly had Major Yuri Gagarin's single-orbit in Vostok-I been appraised than we were presented on 6 August with the 17-orbit mission of Major Gherman Titov who not only endured and ate in orbit but worked the spacecraft's orientation controls and even slept for a time under weightless conditions. For the record, Vostok-II's orbit had an apogee of 152 miles, a perigee of 114 miles, an initial period of 88·46 min. and an inclination to the equator of 64° 56'. The total flight time from lift-off to touch-down was 25 hr. 18 min.

On the American side, the two sub-orbital missions performed by Cdr. Alan Shepard and Capt. Virgil Grissom in Mercury capsules, projected by the veteran Redstone, have proved outstandingly successful, and the full-orbital shot of the Atlas-boosted MA-4 capsule containing a crewman simulator on 13 September has done much to raise hopes that an American astronaut will be in orbit within the next few months. But first a chimpanzee is to be the occupant of capsule MA-5, which is scheduled to make three circuits of the Earth on or about 31 October.

Such is the pace of progress in the U.S.S.R., however, that we should not be surprised to find another Vostok in orbit, perhaps for several days, before the year is out, while the launching of "improved multi-stage boosters" from the Soviet Union into the Central Pacific this September has been an obvious sign of still more exciting things in store. What these latest firings portend can only be conjectured at the present time, but Soviet scientists (and Major Titov himself) have been speaking of the coming possibilities of space stations—in the first instance, presumably unmanned and remote-controlled. There may also be experiments in orbital rendezvous, leading to spacecraft refuelling.

Indeed, there are many possibilities. One is a soft-landing Moon probe. The extension of biological research deeper into space to investigate the effects of the radiation belts and sporadic solar flares is another. Experiments in modifying departure trajectories to skirt the radiation belts via the poles may also be in prospect.

Whatever the next steps may be, it is evident that the elaborate Co-ordinating Computing Centre which has been established in the U.S.S.R. for plotting spacecraft trajectories and serving as a communications link will have a leading part to play. The rôle of this Centre in the 17-orbit Titov mission will be the subject of a special article in our next issue.

K. W. G.

PRINTED IN GREAT BRITAIN

A Ten Year Programme of Space Technology*

By L. R. SHEPHERD,† B.Sc., Ph.D.

The exploration of space represents a new epoch in the development of mankind, and nothing could be more important than that this new step in human history should take place on a fully international basis. At the present time the basis of astronautics is far from international; the situation is dominated completely by the two largest nations in the world and the avowed objective of both of these countries is to try to be the first *nation* in space. This is an unsatisfactory situation that can only be remedied by a special effort on the part of other states to enter space on a co-operative basis.

It is, perhaps, an advantage, from a world standpoint, that other nations, individually, are quite incapable of entering the space race as real competitors of the U.S.A. and U.S.S.R., for it creates the situation that, if other peoples wish to participate in the great adventure of exploring space, they must lay aside purely national ambitions and get together in a joint enterprise where the adventure and the scientific technological and commercial rewards are fully shared. Of course, any group of nations wishing to proceed in this manner, must have at its disposal a level of technology and industrial resources comparable with Russia or America. This condition would be amply fulfilled if the nucleus of such a group were made up of the nations of Western Europe. Such a nucleus would provide a formidable array of industrial power which would be quite equal to that of either of the two existing space powers.

While collaboration between the nations of Europe would be, in itself, a very important step forward, a still more significant end would be served if they took the opportunity of encouraging world-wide collaboration by making the membership of their enterprise open to any country in the world that might wish to join. An open policy of this kind could lay the foundation for a truly international advance into space, for not only would it open the door for the citizens of small countries anywhere in the world, but it could, by its eventual success, encourage the space-capable nations of America and Russia to throw their own vast resources into a common pool.

Such a proposal, more ambitious in its philosophy than the mere establishment of a European third space power, should be no less ambitious in its scope. The joint undertaking should embrace the development of astronautical science and technology in the broadest possible manner, and make the fullest use of the combined economic resources of its members in order to achieve this objective. It should not dissipate its resources in a wasteful and inefficient manner, however, but should proceed on the basis of a careful assessment of the best route to follow in the conquest of space, and this route should be followed with singleness of purpose.

A useful assessment must look some way into the future; too many of our technological enterprises flounder because their authors have looked only to the short-term requirements. In the author's view, a large space programme should be planned in its broad outline for about 10 years ahead. This does not imply that during such a period one should stick rigidly to the technical principles that applied at the outset, but rather that one should adhere to the main targets and only deviate from the prescribed means of achieving these when the technical situation demands.

While accepting that the proposed internationally-based "third-programme" in space should have no less ambitious goals than those of the U.S.A. or U.S.S.R., one must accept the situation that is created by a late start. There could be no question of indulging in the race to the Moon, which appears to be of such paramount importance to our Russian and American friends. This is not particularly important in the long run; of much greater importance is the need for European countries, and any other nations who are prepared to join with them, to play the fullest possible part in the exploration of space without very much regard for timetables. The "third-programme" should be planned so that the participating nations will achieve, jointly, what might be termed full space capability.

The present state of our knowledge is such that we can plan a programme to cover the next 10 years, which will lead, in due course, to the achievement of this full space capability with the maximum economy of effort.

Technical Scope

At the time of writing, the nations of Western Europe are on the verge of participating in a programme to develop, over a 5-year period, a launching vehicle of size and payload capacity comparable to the largest presently operational in the U.S.A. Such a vehicle is adequate for the purpose of carrying out many important exercises in space research and the initial steps in the development of communications satellites. It should be sufficient, furthermore, to launch manned vehicles into sub-orbits and, thereby, take the first steps in the most important of all space enterprises, namely, manned spaceflight. However, it is important to appreciate at the outset the limitations of this vehicle and, as soon as possible, to take the steps leading to the development of larger and more powerful rockets. The space vehicle

* *A contribution to the European Symposium on Space Technology, 26–28 June, 1961.*

† *Past President of the British Interplanetary Society.*

and its propulsion system is the nucleus of all astronautical endeavour, and it must be the main concern of any space programme to ensure that there will be a logical and continuous development in this area.

In its most simple terms the goal in vehicle and propulsion system development is to increase payload capacity and improve the economics of any given mission. At present we are thinking, in Europe, in terms of close-orbit payloads of about 1 tonne, while the present generation of Russian vehicles and the next generation of U.S. vehicles (Saturn) are already almost an order of magnitude beyond this in their capacity. A still further increase by an order of magnitude, at least, would be essential to render possible the exploration of the Moon and planets by man. The first and most important long range objective of a European space programme must be to lay the foundations for the eventual development of vehicles capable of carrying these much greater payloads into space; a reasonable target being to achieve 10-tonne close-orbit payloads by the end of a first 10-year programme, and to have in view the further order-of-magnitude increase towards the end of a second comparable period.

The achievement of great payloads can be a matter of brute force, *i.e.*, of building proportionately bigger launching rockets. Present generations of rocket vehicles can convey, into close-orbit, payloads of about 1% of the all-up-weight of the vehicle. However, this becomes a costly business, if one begins to think in terms of the later payloads mentioned above. Perhaps the question which we should ask at the outset of a European programme is not "How shall we carry 10-tonne payloads into orbit in 1970?" but "How shall we carry 10 tonnes in 1970 as cheaply as we carry 1 tonne in 1960?" It is the solution to the last question that is the important one in astronautics for it will determine, in the long run, the future scale of man's operations in space. In pursuit of this objective the longer term projects of a European programme should look to the more immediate possibilities, such as the use of liquid hydrogen as a fuel; recoverable vehicles and large inexpensive solid propellent boosters. Of these alternatives the use of liquid hydrogen fuel seems to offer the greater possibilities, and the author considers that it would not be unreasonable to consider as an objective for the end of the first 10-year programme the development of liquid hydrogen engines of up to 100,000 kg. thrust and the design of a vehicle using a small cluster of these in its first stage.

A further stage of improvement beyond the chemical liquid hydrogen fuelled rocket might result from the application of nuclear energy in rocket engines. Some long term effort should certainly be directed in this direction and also to the possible, if remote prospect, of developing very energetic metastable propellents.

In the foregoing the emphasis has been placed on vehicles and propulsion systems, because these are completely fundamental to the development of spaceflight. Scarcely less important, however, is the question of re-entry, particularly in connection with manned spaceflight. A European programme should pay due attention to this aspect of astronautics and to the problems of flight at very high speeds in the upper atmosphere. This is an area which does not demand such great expenditure as the vehicle and propulsion work, and many centres of aerodynamics in Europe are already well equipped to deal with it on a greater or smaller scale.

It is not necessary to place special emphasis upon the work which must be done in navigational and control equipment. This must obviously meet the requirements of the vehicles which are developed, and the missions for which they are intended. Similarly, in the areas of instrumentation, electronics and ground equipment of all kinds. These would be by no means new fields for the nations of Europe, some of which already hold a strong position in, for example, the radio tracking of interplanetary vehicles and satellites.

The foregoing comments have been concerned with the salient features of the technology of flight in space.

Summary of Main Points in a Ten Year European Space Programme (1961–1971)

A. Vehicle Projects

1. Phase 1 launching vehicle (the presently proposed project based upon Blue Streak).
2. Phase 1a launching vehicle, utilising higher energy propellents (i.e. liquid hydrogen/lox.) in upper stages to increase payload capacity, but with same first stage as Phase 1 vehicle.
3. Phase 2 launching vehicle, capable of placing 10,000 kg in a close orbit, based entirely on high energy-propellent stages, possibly with 500,000 kg total thrust cluster of liquid hydrogen/lox. engines in first stage.

Associated with these three main projects there would be the development of a small number of appropriate upper stages, some of them interchangeable between the three vehicles listed.

B. Applications

1. Instrument-carrying satellites and space probes for space research, utilising Phase 1 and, in later stages, Phase 1a vehicles.
2. Soft-landing instrumented lunar probe utilising Phase 1a vehicle.
3. Close and Synchronous-orbit communications satellites. Series of launchings and tests leading to commercial use by circa 1970; utilising Phase 1 and 1a vehicles.
4. Development of manned capsule or re-entry vehicle and its use with the Phase 1 vehicle for sub-orbital flight.

C. Research and Development

1. Full supporting research and development in all relevant areas connected with the Projects and Applications listed above.
2. Longer term research and development particularly on advanced propulsion systems that might be used in a second ten-year European programme, e.g. in nuclear propulsion.

The total cost of the above programme might amount to £500 million, of which more than half would be associated with the vehicle development and its associated research and development.

Some remarks must also be paid to the applications to which the vehicles will be put in the course of a 10-year programme. In brief these would include:—

(i) pure scientific research with satellites and space probes;

(ii) civil and commercial applications, notably to communication meteorology and navigation;

(iii) manned space operations.

A great deal has been said and written about space research, and it may be noted that the European framework for collaboration has been set up in this field. In the view of the writer attention should be given not only to satellite space probes, but also to small instrument payloads that might be landed on the Moon. These already figure prominently in the American programme, and there are good reasons for including them in the later stages of a 10-year European programme.

On the question of commercial applications, it may be said that in such an expensive enterprise as space exploration it is of obvious importance to pay due attention to those applications which will lead to a valuable commercial reward. However, it is always important not to do this at the expense of the broader, longer term objectives which may hide, unforeseen, much more valuable prizes. In the course of a 10-year programme one would expect to be able to set up a commercial network of communications satellites which would begin to bring in revenue and contribute usefully to world communications.

Manned spaceflight is, ultimately, the most important outcome of all our astronautical endeavours and, if it did not figure prominently in a European programme, the latter would have no real purpose. Man in space demands large launching vehicles, and it would not be until the later stages of the 10-year plan that serious orbital operations could be contemplated. However, sub-orbital flights by manned capsules would certainly be possible even with the presently proposed European launching vehicle, and these would be valuable in training "astronauts" and gaining experience for later true space operations. Some launching vehicles should be earmarked for this purpose, the necessary re-entry vehicle developed, and supporting work in space medicine and crew training should be included in the programme.

Organization

The cost of a programme as ambitious as that outlined in the previous section would not be negligible. It is hardly likely that this could be carried out, over the period in question, for an average expenditure of less than £50 million per year. Several projects based upon different centres in Europe and launching sites elsewhere in the world, *e.g.*, N. Africa and Australia, would be involved. The problem of efficient direction, control and administration would be considerable, and it would certainly necessitate the establishment of a new organization which could take full legal and financial responsibility for the execution of the work.

There are many forms that might be taken by the central organizing body. At the one extreme it could take the form of a supra-national authority, such as E.U.R.A.T.O.M., at the other it might be an Agency comparable to the European Nuclear Energy Agency of O.E.E.C. If only one centre were involved, one might set up an organization such as C.E.R.N., but this would not be applicable in the case of the wide programme outlined above.

Having regard for the relatively loose political association of the participating countries, particularly if non-European states associated themselves with the programme, the establishment of a powerful supra-national authority would not be appropriate. In the opinion of the writer, the proper procedure would be to set up, possibly under O.E.E.C., a European Space Development Agency. The first task of such an Agency would be to decide, in consultation with the experts from participating countries, the scope and cost of the programme. The next step would be to divide the work into a number of projects and development areas, and to allocate each of these to a centre in one of the participating countries. The centres could be existing national research establishments which would become internationalized in the sense that they would open their gates to staff from any of the other countries. Obviously, a fair distribution of the various projects would be made throughout the participating countries, and contracts should be placed on an international basis.

The question would arise as to the respective roles and responsibilities of the European Space Development Agency, and the various centres involved in the programme. While there is some scope for variation of the respective responsibilities, the most workable arrangement would be to give each centre full responsibility for the conduct of the work in its own project or area, including the financial and contractual actions which would have to be taken. The Agency would not, itself, exercise any close technical control, nor would it intervene in the day to day administration of the work at any centre. It would be represented on any of the international managerial committees which, inevitably, would be involved in all projects, and would otherwise be responsible for planning the overall programme. Once a project had been started at a given centre it should be allowed to proceed without interruption over an agreed period (say 5 years), with an agreed budget for the whole period. Obviously, it should not be forced to proceed on the basis of an uncertain budget covering only short intervals with no guaranteed continuity.

The preceding organisation corresponds fairly closely to that which already exists in certain European joint programmes, and it has been found to work. There are, of course, a variety of possibilities which would place more or less responsibility in the hands of the Agency. However, the proposals outlined, very briefly, in the foregoing paragraphs would appear to the writer to represent a reasonable compromise between the need for having some central control, and the equal need to leave the technical decisions in the hands of the people who would have to execute the project.

Liquid Propellent Motors*

By W. N. NEAT, A.F.R.Ae.S.

Introduction

A rocket engine is a device to convert chemical energy into kinetic energy and thus produce a propulsive effect or a thrust. Both the internal combustion engine in a motor car, and the gas turbine engine in a jet aircraft, actually meet these definitions.

In the motor car engine, however, air is taken into the cylinders and used to burn the fuel. The energy released is then transmitted through the transmission to the rear wheels as shaft power. In the gas turbine engine air is again taken in to burn the fuel, but here the resultant gases are expelled in the form of a high velocity jet, and the propulsive effect is obtained by the reaction of this jet.

The rocket engine is similar to the gas turbine in so far as it is a reaction device, but it differs from both the gas turbine and the reciprocating engine in that it does not take in any atmospheric air, but instead carries all its means of propulsion within itself.

General Characteristics

This then is the most important thing to know about a rocket engine. It not only carries its fuel, but in some form of chemical, it also carries the oxygen with which to burn that fuel. For this reason a rocket engine is to all intents and purposes unaffected by its environment and can successfully operate at high altitudes where the air is very thin, or out in space where there is not any air at all.

As an analogy, let us consider a man in a boat on a canal, and assume that he is propelling the boat by throwing bricks backwards over the stern. The bricks then correspond to the stream of gases being discharged from a gas turbine or rocket engine. Now the bricks could be distributed in a row along the edge of the canal, with the man picking them up, and throwing them backwards as he goes along. This is like the gas turbine, in which air, corresponding to the bricks, is taken in all the time. You will note than when the supply of bricks end the man cannot propel the boat any further by this means.

Now let us consider the other case of the man having a pile of bricks in the boat with him instead of along the bank of the canal. He can now propel the boat quite independently of his surroundings. This corresponds to the use of rocket propulsion, but you should note that in this case, the boat initially, is far more heavily loaded. By analogy, therefore, while it is independent of its surroundings, a rocket engine has to be fed with far more chemicals than the gas turbine has to be fed with fuel. This fact alone generally confines the use of rocket engines to rather short periods of operation.

Thrust Generation

Let us now consider in somewhat more detail how the rocket engine produces its thrust. Let us consider a sealed pressure vessel such as a balloon, the neck of which has been securely tied. The pressure in the balloon acts uniformly in all directions, and consequently there is no force trying to make the balloon move one way or another. If now we suddenly open the neck of the balloon, we find that, as indeed one would expect, the air rushes out and propels the balloon in the opposite direction. This has been caused by the pressures inside the balloon being modified as the air rushes out giving an unbalanced force. On the side of the balloon opposite the open aperture there is a small pressure force unbalanced by a similar force at the open aperture; this out of balance produces a force which propels the balloon, as you have seen, in no uncertain manner.

There is another way of looking at the generation of this force by using Newton's Laws of Motion. As the air accelerates through the aperture a force has to be applied to it to give it its increasing velocity. To every action we know there has to be an equal and opposite reaction, and it is this equal and opposite reaction that propels the balloon. The balloon is indeed a very simple form of rocket engine combustion chamber, but as you can imagine it is much too crude for any practical use. To begin with, the energy it contains is too small to produce any really worthwhile thrust. Secondly, the conversion of pressure energy of the air in the balloon to kinetic energy of the air leaving the balloon is very inefficient. Finally, there is no way of continuously recharging the balloon so that it goes on propelling itself for any length of time.

These limitations can be overcome in the combustion chamber of a rocket engine, which I have already said can be likened to the balloon. To overcome the very short and rather explosive nature of the balloon's behaviour, chemicals can be continuously fed into the combustion chamber where they burn without interruption, generating a steady supply of gas. If the

** A lecture prepared for the B.I.S. one-day course for Teachers on Rocket Propulsion Technology, held in Birmingham, on 30 March, 1961.*

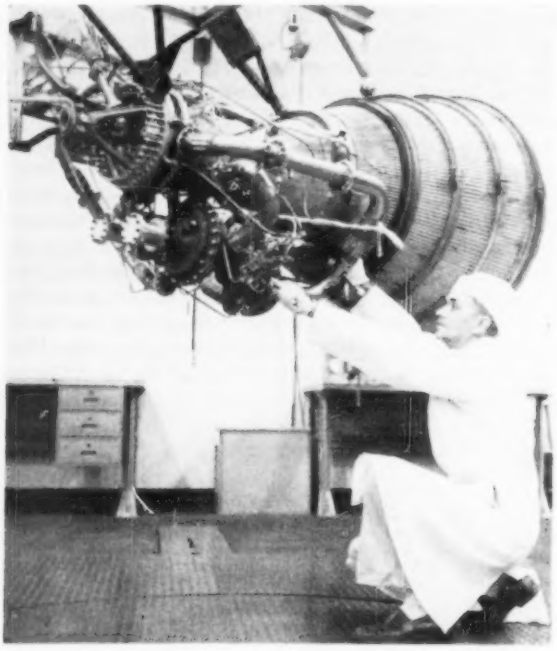
chemicals are liquids they can conveniently be injected into the chamber under pressure, and as a great deal of heat is generated in the combustion process a large amount of high temperature, high pressure gas is formed.

Liquid Propellents

The chemicals used are known as propellents, and these are generally divided into two sorts. There are oxidants which contain oxygen or an oxidizing component, and fuels which burn with the oxidants, releasing energy in the process. You have already heard quite a lot about propellents, and I will have more to say about them later.

There are a number of added advantages in using liquid propellents in a rocket engine. To begin with, it makes it possible to vary the thrust by varying the flow of propellents into the chamber. Furthermore, by suitable design, it is possible to cut the flow completely, so stopping the rocket engine and then to re-start it again later, perhaps a large number of times. In addition, as I will explain later, one of the propellents can be used as a coolant to keep the combustion chamber at a reasonable temperature.

Whereas the performance of modern liquid propellent engines is not very different from those using solid propellents, of which you will hear more later, those giving the highest performance, which will be needed for the more ambitious journeys into space, will almost certainly use liquid propellents, because they are the only substances we know of which contain enough available chemical energy.



Inspecting the Pratt and Whitney LR-115 rocket engine, the first such unit developed in the United States to employ liquid oxygen and liquid hydrogen. It delivers a thrust of 15,000 lb. Twin engines are embodied in the top stage of Atlas-Centaur.

Pratt and Whitney

The maximum amount of heat and pressure energy in the combustion chamber is converted into kinetic energy by a suitably designed nozzle or aperture. You will note that this has a particular convergent/divergent shape with a throat of a comparatively small diameter, this shape being necessary when a supersonic jet has to be formed. The velocity of the gas stream at the throat is equal to the local speed of sound, and in the subsequent divergent part of the nozzle the gases go on accelerating to supersonic speeds. In actual fact, the size of the throat determines the pressure/flow relationship in the combustion chamber. As soon as the jet becomes supersonic no pressure waves, which themselves travel at the speed of sound, can pass up the gas stream, and this means that external pressure and temperature cannot in any way influence conditions in the combustion chamber. This is another reason why a rocket engine is independent of its surroundings.

Theoretical Considerations

Let us now consider a few basic equations which decide what happens in the combustion chamber and nozzle. Momentum theory tells us that thrust is proportional to the rate of change of momentum. This means that

$$T = \frac{Wv}{g}$$

where T is the thrust produced, and W the weight of propellents passing through the chamber every second, v the velocity of the gas leaving the nozzle, and g the acceleration due to gravity.

Remembering that the rocket engine is by its very nature, a thirsty device, the rocket engineer is mostly interested in getting as much thrust as he can for as small a flow of propellent as possible, and he would therefore re-write this equation

$$\frac{T}{W} = \frac{v}{g}$$

He would want to make the left-hand side as large as possible, and as you can see, this means that the exhaust velocity on the right-hand side must also be as large as possible. This, indeed, is the criterion for an efficient rocket engine.

Let us now consider the factors on which exhaust velocity depends. Using the gas laws, the mechanical equivalance of heat and Bernoulli's equation for the expansion of the gases in the nozzle, we can write

$$v = \sqrt{\frac{\gamma}{\gamma - 1} \frac{G\theta}{m} \left\{ 1 - \left(\frac{1}{r} \right)^{\frac{\gamma - 1}{\gamma}} \right\}}$$

In this equation γ is the ratio of the specific heats of the gases formed in the combustion process, G is a constant

incorporating among other things the mechanical equivalent of heat, θ the temperature of the gases when they burn, m their average molecular weight, r the pressure ratio over which they are expanded.

From this equation you will see that exhaust velocity depends on all these factors to a greater or lesser extent. Simplifying somewhat, we find that in the main, the higher the temperature and pressure in the combustion chamber, and the lighter the gas formed, the higher the exhaust velocity will be.

Combustion Chamber Pressure

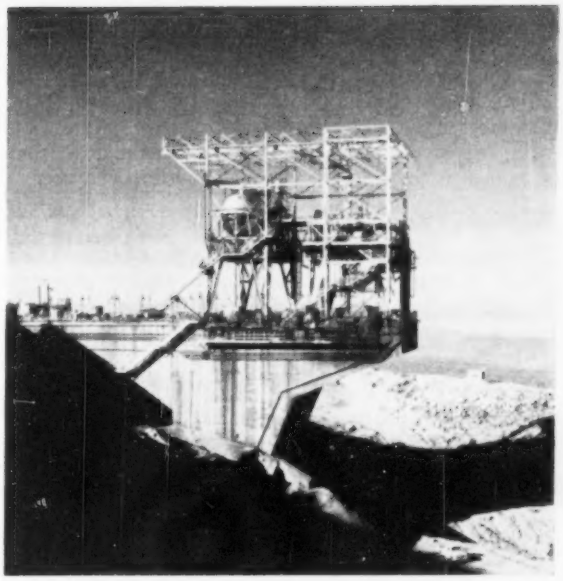
Combustion chamber temperature and molecular weight depend on the propellents being used, while combustion pressure depends on the design of the rocket engine. Consider first the effect of pressure. In most designs this is usually a compromise, for whereas a high pressure in the combustion chamber leads to a high exhaust velocity, it also introduces higher stresses and other engineering difficulties. With nothing else being altered, if one plots exhaust velocity against pressure, one finds it increasing rapidly at first, and then tends to level out, so that when a certain pressure is reached there is little further gain in exhaust velocity by increasing it much more. In general, it is fair to say that most rocket engines work at a pressure beyond which there is little further gain in performance.

These pressures are, however, fairly high, usually between 500–1000 lb. in.^{2} This means, therefore, that special means have to be provided to force the propellents into the combustion chamber. The pressure required to do this is usually a few hundred lb. in.^{2} higher than the pressure in the chamber itself, because in order to get the propellents burning happily it is necessary to atomize and thoroughly mix them. This can usually best be done by forcibly injecting them through a large number of small holes in the head of the combustion chamber with a fairly large pressure drop across each hole.

The propellents have therefore to be supplied to the combustion chamber at a high pressure, and this can be done in two ways, either by pressurizing the tanks which contain them, or by pumping them with mechanical pumps.

Tanks can be pressurized with air or nitrogen or helium, but this means that since they have to withstand a high pressure their walls will have to be thick, and they will be heavy, especially if they are large. In addition, there is the weight of the pressurizing gas and the containers for it. Pressurized rocket engines of this type have the virtue of simplicity, since they have no rotating parts, but because of their heavy tanks they can generally only be used in small sizes and for short periods of time.

The use of mechanical pumps largely overcomes this disadvantage, since the tanks then need withstand only the small pressure necessary to force the propellents into the pumps. Consequently they need only be of light construction, and this form of propellent feeding is usually mandatory for large rocket engines which have to run for a long time.



Test stand for the 1·5 million s.t. Rocketdyne F-1 engine at Edwards Air Force Base, California.
North American Rocketdyne

Because of the large flows involved, and the fact that high pressures are required, the pumps used are of the centrifugal type. Each propellent is fed into the centre of what is in effect a suitably designed paddle wheel, which centrifuges the liquid outwards. As it does this the pressure in the liquid rises, and furthermore the high velocity at which the liquid leaves the rim of the paddle wheel is converted by means of a diffuser into even more pressure.

These centrifugal pumps are invariably driven by a turbine which itself is fed by gases formed by burning some of the propellents in a small auxiliary combustion chamber or gas generator. If the propellents were burned in the same proportion as they are in the main combustion chamber, the resulting temperature would be much too high for the turbine to stand. So an excess of one or other of the propellents is used, and this excess does not burn, but merely vaporizes and cools the gas to an acceptable temperature. Once the gas has done its job in the turbine it is exhausted through a nozzle, from which a small but useful amount of thrust is usually obtained.

Sometimes the turbine drives the pumps directly, but often they have to run at different speeds and a gear box is therefore required. One of the main problems with such pumps is that of sealing, in order to prevent the propellents leaking down the drive shafts. This is important, since rocket propellents by their very nature are usually corrosive or inflammable, and it is therefore

dangerous to have them loose about the place.

The turbo-pump system of a rocket engine, once it has been started, is self-sustaining. This is done by feeding the gas generator with a small flow of propellent from the pumps. This flow is, of course, only a very small part of the total flow, since the main flow from the pumps is fed into the main combustion chamber.

Combustion Chamber Temperature and Cooling

We have now seen how in order to get a high exhaust velocity it is necessary to use a high chamber pressure, and we have considered one or two ways of obtaining this. Let us now think about the temperature in the combustion chamber.

Going back to the equation for exhaust velocity, you will remember that

$$V \propto \sqrt{\theta}$$

A high chamber temperature is therefore even more important than a high pressure. The temperature at which the gases are formed depends very largely on the propellents being burned. Before considering the propellents themselves, however, let us consider how the combustion chamber is made to accommodate a high temperature. In most rocket engines this is of the order of 3000° C., which is about 1500° C. higher than the melting point of the materials from which the combustion chamber is made, and even more in excess of the temperature at which these materials have any appreciable strength. Such combustion temperatures can only be tolerated by continuously cooling the chamber in rather the same way that water is used to cool the engine of a motor car.

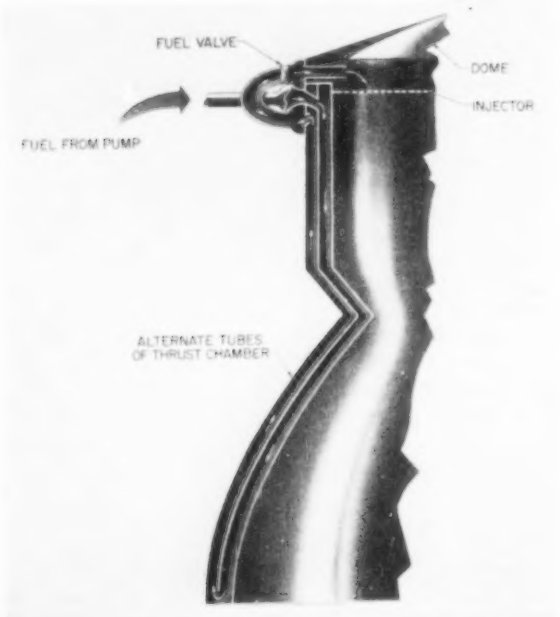


Diagram illustrating fuel flow through the F-1 combustion chamber.

North American Rocketdyne

Water cooling in a rocket engine is, however, not practicable. In the first place such a system would be very heavy, and in the second place, for a rocket engine working at high altitude or out in space, there would not be enough air to keep the radiator cool. Consequently, in a rocket engine, it is necessary to use one or other of the propellents for cooling, circulating it around the outside of the combustion chamber before it is injected into the chamber and burnt.

The high propellent flow rate is here an advantage, and most chambers can be kept sufficiently cool with a propellent temperature rise of less than 50° C. as it traverses the coolant passages.

No coolant system would work at all were it not for the fact that, adjacent to the wall, a stagnant boundary layer of gas is built up in the chamber. There is a marked temperature drop through this layer, notwithstanding that it is only a fraction of an inch thick, so that the wall of the chamber is not exposed to anything like the full combustion temperature. This boundary layer is thinnest at the throat section, and consequently this is the most difficult area to keep cool. When combustion chambers burn out as they sometimes do, this is where it usually happens.

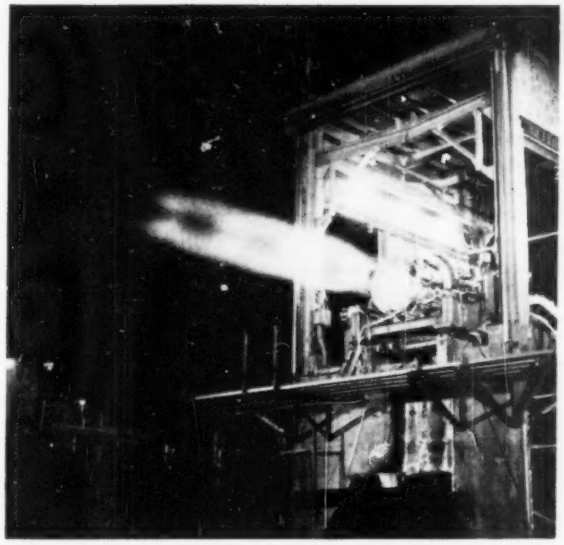
There are ways and means of increasing the effectiveness of the boundary layer. One is to inject small quantities of propellents into it through minute holes in the chamber wall. The propellent injected vaporizes and so increases the thickness of the layer, thus increasing its insulation qualities. Additionally, as the injected liquid vaporizes, it absorbs its latent heat, and thus generally reduces the boundary layer temperature.

In the early days combustion chambers were made as two separate parts, the inner shell and the outer jacket, the annular space between the two becoming the passage for the coolant. This was a rather heavy method of construction, and combustion chambers of current rocket engines are generally made of a large number of specially shaped tubes, which are then brazed or welded together, to form the complete chamber. Each tube acts as a separate cooling passage, and as its wall thickness need only be about one-hundredth of an inch, a lightweight assembly can be obtained.

We have now dealt with combustion chamber pressure and temperature, and the means for accommodating these. Let us now consider the sorts of chemicals which are used as propellents.

More About Liquid Propellents

These can be broadly divided into three categories. Firstly there are those which do not ignite spontaneously when they mix. Consequently some sort of igniting device, such as a firework or spark plug, has to be provided in the combustion chamber to initiate combustion. Once this is done the propellents will go on burning together for as long as they are injected. In this category are the oxidants, liquid oxygen, nitric acid,



Static firing of the Thiokol LR-99 rocket engine used in the highly successful North American X-15 research aircraft. It is constantly throttleable over a thrust range of 25,000 to 50,000 lb., and is capable of repeated restarts.

Thiokol Corporation

or hydrogen peroxide when burnt, for example, with petrol or paraffin.

In the next category come those propellents which ignite spontaneously when they are brought together, and for which therefore no igniting device is needed. As examples of these we have nitric acid with aniline, or hydrogen peroxide with hydrazine. Self-igniting propellents of this type simplify the combustion chamber and generally lead to smooth combustion, but they do impose the risk of a fire should they accidentally mix outside the combustion chamber. Hydrogen peroxide used with kerosine can be made into a sort of self-igniting system, since peroxide, prior to injection into the chamber, can be catalytically decomposed into super-heated steam and oxygen so hot that when the kerosine is injected into it, it spontaneously ignites.

In the last category we have the mono-propellents, chemicals which can be burnt and decomposed on their own to form a sufficiently large quantity of gas. Hydrogen peroxide by decomposition comes into this category, while nitromethane and isopropylnitrate are more energetic examples of mono-propulsion.

Generally speaking, if mono-propellents are safe to store and handle, they do not contain enough energy to give them a worthwhile performance. On the other hand, if they are sufficiently energetic, then they usually impose difficult safety problems.

The choice of propellents is invariably a matter of compromise to suit the particular application being considered. Of the oxidents, liquid oxygen is widely used for large ballistic missiles, mainly because it gives a high performance, is cheap, and fairly easy to handle. Nitric acid has been used for small missiles, because like liquid oxygen it is cheap, although unlike liquid oxygen it has a low boiling point, and can therefore be stored for long periods of time even in sealed containers. Hydrogen peroxide has been used for rocket engines in manned aircraft mainly because it can be decomposed before injection into the combustion chamber, this feature leading to a safe system and facilitating the variable thrust requirement and the need for repeated use.

Of the fuels, petrol and paraffin are widely used because of their familiarity and availability. All the propellent combinations so far described burn at temperatures between 2000° and 3500° C., giving exhaust velocities varying from 6000 and 8000 ft./sec.

There are, however, a number of other propellents which because of the improved performance they give, and other characteristics they possess, are also now in use. As oxidents, nitrogen tetroxide, chlorine trifluorine and even fluorine itself are being worked upon, while as fuels, hydrazine and liquid hydrogen are among the most interesting.

The liquid hydrogen/liquid oxygen combination is one of which you should take especial note. With the exception of fluorine and hydrogen, this combination gives the highest possible exhaust velocity, namely about 11,000 ft./sec. and consequently is likely to be quite widely used in future for space exploration. To appreciate why this is so, one must go back again to the equation for exhaust velocity and note that

$$V \propto \sqrt{\frac{1}{m}}$$

This means that the lower the molecular weight of the gases formed in the burning process, or in other words the lighter they are, the greater the exhaust velocity will be. Oxygen and hydrogen produce gases, mainly, of course, super-heated steam, which have a molecular weight appreciably lower than those formed from any other propellent combination. As a result, these two chemicals used together produce a very high exhaust velocity, without actually burning at a very high temperature.

The Nuclear Rocket Engine

Liquid hydrogen by itself has another interest, since it is a very suitable propellent for a nuclear rocket engine which does not rely on the release of chemical energy, but instead heats all its working fluid using the energy of an atomic pile. Since no chemical reaction is involved, there is therefore a greater freedom in choosing the working fluid, and since in the nuclear rocket, as well as in the chemical one, exhaust velocity depends on molecular weight, you will appreciate why hydrogen is a suitable propellent. Using it and heating it up to as high a temperature as we can imagine an atomic pile working, exhaust velocities can be obtained which are three or four times greater than those possible in the best chemical rockets. This really means that a

nuclear rocket will consume far less propellent, and this will have a great effect on the practicability of many space missions. In fact, there are many such missions quite impossible with chemical rockets, which could only be accomplished by using nuclear propulsion of this type.

Still More About Propellents

Let us now go back to propellents for chemical rockets. In choosing these, high exhaust velocity is not the only consideration. To begin with, the chosen propellents must be readily available, and preferably cheap. They must be capable of storage, preferably for a long time, and they must be safely handled, preferably without too much difficulty or special equipment. One or other of the propellents chosen must be capable of use as a coolant, and this implies a high specific heat and a low vapour pressure. Low vapour pressure is also of value in designing the pumps, while a high liquid density reduces the size and weight of the tanks. Needless to say, no single propellent meets all these requirements, and the choice is always a compromise, depending to a great extent on the particular use which is going to be made of the rocket engine.

The Choice of a Rocket Engine

I have mentioned the combustion chamber, the turbine, the pumps, and the tanks. These are the most important parts of a rocket engine system, but there is one other part we must not forget. This is the control system, regulating the flow of propellents from the tanks through the pumps and into the combustion chamber. This system has to fulfil a number of requirements. It must first of all ensure that on starting up the propellents reach the combustion chamber at the right time, and in the right sequence. While the engine is running it must ensure that the propellents are being burned in their correct ratio one to the other. At shut down it must again ensure that the correct sequence is followed. Under all conditions the control system must ensure safe operation. Remember that an accumulation of propellents contains a large amount of energy, which, if suddenly released at the wrong time and in the wrong place, could wreck the engine, and quite possibly the vehicle it propels.

Conclusion

In conclusion, it might be in order to list the broad requirements of a large liquid propellent rocket engine, and the particular difficulties which face the rocket engineer. To begin with the pumps must be capable of instantly supplying propellent under pressure, and then continue to supply it without fluctuation or interruption. The gas generator feeding the turbine must supply gas at the right temperature, even when flows are rapidly changing, such as during starting and stopping. The entire propulsion system, including the pumps and valves, must be completely leak proof, in spite of the high pressures of the generally corrosive, often freezing cold, or otherwise obnoxious fluids being handled. All the valves must be capable of instantaneous and positive action whenever they are called upon to do so.

The propellents must be injected into the combustion chamber so that they thoroughly mix and completely burn. Any propellent which leaves the combustion chamber unburnt is not making its full contribution to the efficiency of the engine. The injector system must be such that not only does it permit a smooth start, but also ensures the propellents carry on burning steadily thereafter. With a wongly designed system it is possible to set up pressure fluctuations in the chamber which could ultimately lead to complete failure.

Finally, the chamber itself must be kept sufficiently cool to allow the engine to perform its allotted task. The problem of heat balance through the chamber wall into the coolant is a critical one, the solution of which demands great care and ingenuity.

As you can see, the rocket engine contains a number of challenging problems. These have not yet been entirely solved, even for the present generation of engines, and the use of more energetic chemicals necessitated by the need for improved performance will bring new problems in its train. This is one reason why rocket engineering is so interesting.

Engineering Aspects of Solid Propellent Motors*

The solid propellent motor case is essentially a pressure vessel capable of withstanding a high internal pressure with perhaps superimposed bending loads. Parts of the case may be subjected to heating by the products of combustion of the propellent or by external kinetic heating due to atmospheric friction.

The complete case is usually built up from the following components:—

(*a*) The cylindrical pressure vessel.

(*b*) A forward attachment for fitting the igniter and thrust take off.

(*c*) A rear end closure.

(*d*) A nozzle consisting of the throat and expansion cone.

The case may be provided with an internal layer of thermally insulating material and the nozzle is usually made from materials possessing adequate thermal properties rather than high mechanical strength.

In order to achieve high performance it is necessary to reduce the weight of the rocket motor case to a

* *Summary of a paper presented at the B.I.S. one-day course for Teachers on Rocket Propulsion Technology, held in Birmingham on 30 March, 1961.*

minimum whilst retaining sufficient mechanical strength and stiffness.

Materials of Construction

The materials of construction fall into two groups, those possessing high strength/weight characteristics and those possessing specific thermal properties suitable for use in those parts of the motor which attain high temperature during operation.

The most useful materials possessing high strength weight properties are at the present:

Alloy steels.

Titanium alloys.

Resin impregnated glass fibre structures.

Amongst the materials used for their thermal characteristics are the high-melting point metals molybdenum and tungsten and refractory materials such as carbon and silicon carbide. Resin impregnated asbestos fibre is frequently used as a thermal insulating medium which also possesses reasonable strength together with the ability to be formed relatively easily into complicated shapes.

Material development has been actively undertaken for a number of years and many methods of evaluating materials on a laboratory scale have been used. High strength metallic materials generally exhibit a ductile/brittle transformation characteristic under certain conditions and although uniaxial tensile testing techniques are useful, biaxial tests are necessary to provide information on brittle behaviour. Notched tensile testing is also used to provide information on material properties and the presence of impurity elements in high tensile steels has been shown to exert a considerable effect on mechanical reliability.

It is difficult to devise adequate laboratory tests for refractory materials as the performance of a material in a rocket nozzle will depend upon its ability to withstand thermal shock and sustained high temperature together with chemical attack and erosion.

The improvement of rocket motor performance usually involves the use of propellents producing high temperatures which impose increasingly severe conditions on the refractory and insulating materials used. Further decreases in the weight of the inert parts require the use of improved high strength materials. The difficulty of increasing the modulus of high strength materials may lead to lack of stiffness in the rocket motor case unless adequate attention is given to methods of increasing structural stiffness by careful design.—F. J. Wilkinson, Bristol Aerojet Limited, Banwell.

High-Energy Chemical Propellents*

By F. FITZGERALD, B.Sc.(Tech.), PhD., A.M.Inst.F.†

For military purposes, rocket propellents at present in widespread use, both solid and liquid, appear to be adequate. There is, however, a field of application for high energy propellents based on the use of fluorine, hydrogen, etc., for space research; *e.g.*, upper atmosphere research; launching of space laboratories; the establishment of space platforms, etc. It is against this background that this paper reviews the field of high energy chemical propellents.

The theoretical and practical properties desired of rocket fuels and oxidizers are discussed briefly and then those elements and their compounds which have high theoretical performance in the rocket and which exhibit some of those characteristics desirable in a rocket propellent are examined. It is seen that there is no truly ideal propellent combination but some suggestions are made regarding the possible use of certain combinations.

Generally, liquid propellents are discussed as, although the solid rocket is simple, it usually costs less than the rocket using liquid propellents, and has other advantages, it is at the present time difficult to control and terminate the thrust developed; also the firing time is short and therefore less total thrust is produced; and the performance of the solid propellents is less than that of the best liquids. The free-radical and ionic rockets and associated systems are not considered, as their future is so inherently bound up with that of nuclear propulsion that the problems are no longer those of chemical fuels.

Theoretical Requirements

The function of a rocket is to accelerate a payload to a prescribed velocity and if at the time the fuel burns out, the payload is travelling with the proper speed in its intended direction, the rocket has done its job efficiently. Thus the criteria of a rocket's performance

* *Based on lectures to the British Interplanetary Society, at Caxton Hall, London, 1959 and The Midland Institute, Birmingham 1960.*

† *Research and Development Department, The United Steel Companies Limited, Swinden Laboratories, Moorgate, Rotherham, Yorkshire.*

are its velocity at the time the fuel burns out (Vc) and the weight of the payload carried for a given rocket take-off weight (Mo). These quantities are related by an equation of the general form:—

$$V_e = V_e \log_e \frac{(M_o)}{(M_e)} \quad .. \quad .. \quad .. \quad (1)$$

(neglecting secondary factors such as time of burning and type of trajectory), where V_e = the propellent exhaust velocity and $M_e = (M_o - m)$, where m = mass of propellent at take-off, *i.e.*, M_e is the "dry weight" of the rocket plus the weight of the payload.

The desiderata of high performance rockets are thus; that V_e and (M_o/M_e) should be as high as possible. Practical engineering difficulties in the manufacture of the rocket restrict the value of (M_o/M_e) and thus our aim is to increase values of V_e. Generally the performance of a propellent in a rocket engine is expressed in terms of the specific impulse:—

$$I = \frac{F}{W} = \frac{V_e}{g} \quad .. \quad .. \quad .. \quad (2)$$

where F is the thrust produced, W the propellent flow rate and g gravitational acceleration. For ideal gases in a rocket nozzle

$$I = \left[\frac{1}{g} \cdot \frac{2\gamma}{\gamma - 1} \cdot \frac{RT_c}{M} \left\{1 - \left(\frac{P_e}{P_c}\right)^{\frac{\gamma-1}{\gamma}}\right\}\right]^{\frac{1}{2}} \quad .. \quad (3)$$

where R, T_c, γ and M are respectively the universal gas constant, the combustion temperature, the ratio of specific heats and mean molecular weight of the combustion products. P_e = the exit pressure of the nozzle and P_c the rocket chamber pressure.

Equation (3) can be split into two parts, one of which is virtually independent of propellent properties and the other denoted by the term X, is controlled by the propellent

$$X = \sqrt{\frac{2R}{g} \cdot \frac{T_c}{M}} \quad .. \quad .. \quad .. \quad (4)$$

To a first approximation therefore

$$I \propto \left(\frac{T_c}{M}\right)^{\frac{1}{2}} \quad .. \quad .. \quad .. \quad .. \quad (5)$$

and a good propellent will give products with a high (T_c/M) ratio.

A high combustion temperature will be given by those elements having a high heat of reaction and a classification of the elements can be made on this basis. Fortunately the elements having high heats of combustion are those with relatively low molecular weights and they occur in those parts of the periodic table, shown in Fig. 1.

So far we have mentioned only fuels, but the oxidizer to be used with the fuel needs to be considered, as the molecular weight of the products of the reaction is important. The most desirable fuel/oxidant combinations consist of elements separated by the greatest horizontal distance from each other in the periodic table, provided that the molecular weight of the reaction products does not become too high; these combinations give the greatest energy release. We normally consider oxygen as the oxidant in any combustion reaction, but other oxidants are possible and in some cases more efficient, *e.g.*, an improvement in rocket performances should be expected if fluorine rather than oxygen were to be used as oxidant. Chlorine has a high molecular weight and with it an improvement would not be expected. The high energy oxidants therefore appear to be limited to oxygen and fluorine, their mixtures, compounds and possibly allotropes, *e.g.*, ozone.

Tables I and II show theoretical performance figures and some physical properties of some of the elements shown in Fig. 1 and their compounds. The generally high performance of fluorine and ozone systems and the superiority of hydrogen as a fuel are immediately apparent.

Physical Requirements

Improvement in the exhaust velocity of the reaction products of the propellent combination is not the only criterion however; to reach a decision as to the most worthy combination other desirable features which a propellent should be expected to have must be considered. They may be listed:—

(1) The density of the propellent combination should be high in order to reduce the size and weight of tanks for a given range of the rocket. The smaller the tank weight and the greater the value (M_o/M_e) the better the performance.

(2) The reaction temperature must not be so high as to cause insuperable chamber cooling problems. Also one of the propellent components should be a good regenerative coolant, *i.e.*, its heat capacity should be high and its thermal conductivity high. It should be thermally stable and its viscosity should be low to prevent excessive pressure drop through the engine coolant passages and consequent large and heavy pumping gear.

(3) It should be non-toxic and it should be insensitive to explosion or detonation; these properties make for easy handling.

(4) The propellent should be capable of being stored easily; large batches can then be produced and remain "on tap" ready for use.

(5) Finally, and this is perhaps the most important point, the propellents should be readily available in large quantities, or the means for their production should be available or capable of development. Whilst some military and research requirements may be satisfied by the use of small amounts of propellents, the large-scale use of rockets will require enormous quantities of materials.

TABLE I.—*Performance figures of some of the elements and their compounds.*

$$\text{S.I.} = \frac{\text{Thrust}}{\text{Propellent Flow Rate}}$$ at 300 p.s.i. chamber pressure. Expansion Ratio 20:1.

Frozen Equilibrium in the Expansion Process.

Propellent	S.I.	Reaction temp. °F.	Wt. oxidant / Wt. fuel	Bulk density
Ozone–Hydrogen	373	4280	2·65	0·23
–Hydrazine	277	5418	0·63	1·20
–Ammonia	267	5157	1·13	1·13
–Kerosene	266	—	1·9	—
Fluorine–Hydrogen	356	4469	3·77	0·269
–Lithium	335*	7000	2·19	0·83
–Hydrazine	300	7692	1·98	1·31
–Ammonia	296	7512	2·9	1·017
–Diborane	291	7880	5·0	1·07
–Kerosene	263	7100	2·9	1·19
Oxygen–Hydrogen	345	3886	2·89	0·23
–Lithium	318	13000	1·15	0·662
–Lithium boro-hydride	306	8300	1·47	0·78
–Diborane	293	7100	1·734	0·72
–Boron	279	12830	2·33	1·49
–Aluminium boro-hydride	276	6000	1·32	0·634
–Lithium hydride	268	6400	1·34	0·975
–Acetylene	266	6012	1·23	0·828
–Hydrazine	263	5382	1·00	1·065
–Ammonia	250	4834	1·25	0·862
–Kerosene	249	5702	2·28	1·02
Oxygen/Fluorine–Kerosene	299	—	—	—
Fluorine monoxide–Hydrazine	295†	6380	1·1	1·23
Hydrogen peroxide–Diborane	290 approx.	—	—	—
W.F.N.A.–Hydrogen	298	5360	12·6	0·6
Nitrogen tetroxide–Hydrogen	279	5610	11·5	0·565
Oxygen/Ozone–Hydrogen	355 approx.	—	3·0 approx.	

* Maintained equilibrium in the expansion process. † Figure for 500 p.s.i. chamber pressure.

The S.I. values are comparative; they would, and could be increased by use of higher chamber pressures.

TABLE II.—*Physical properties of some of the elements and their compounds*

Material	Boiling point °F.	Freezing point °F.	Specific gravity
Acetylene	— 115·2	— 119·2	0·62 (liq.)
Aluminium	3732·8	1217·7	2·70 (68° F.)
Ammonia	— 28·2	— 107·9	0·66 (liq.)
Beryllium	5012·6	2343·2	1·84 (68° F.)
Boron	4622	4172	2·34
Carbon	—	6332	2·25
Diborane	— 135	— 266	0·21
Hydrazine	236	35	1·00 (liq.)
Hydrogen	— 423	— 436	0·07 (— 423° F.)
Kerosene	395/535	— 35	0·82
Lithium	2437	367	0·534 (77° F.)
Magnesium	—	1200	1·74
Silicon	—	2590	2·49
Sodium	—	130	0·97
Fluorine	— 306·9	— 360	1·54 (liq.)
Oxygen	— 297·4	— 362	1·138 (liq.)
Ozone	— 169·4	— 315	1·57 (— 297° F.)

	H (1·008)						
He..	Li (6·94)	Be (9·01)	B (10·8)	C (12·0)	N (14·0)	O (16·0)	F (19·0)
Ne..	Na (23·0)	Mg (24·3)	Al (27·0)	Si (28·1)	P (31·0)	S (32·1)	Cl (35·5)

FIG. 1. Part of the periodic table of the elements. Numbers in brackets are atomic weights.

The requirements listed above are not mutually compatible and in choosing a propellent combination the adjustment and balancing of the advantages and disadvantages of the materials is necessary. With the data shown in Table II and the desiderata of propellent combinations which we have noted we may consider further the possible constituents of propellent combinations.

Fuels

Hydrogen

Hydrogen represents the best chemical fuel and is worthy of detailed consideration. It occurs widely on the Earth's surface and the gas is produced in large quantities by the chemical industry. Recently in the U.S.A. it has become available in large quantities in the liquid form. Hydrogen exists in two forms, *ortho* and *para*, which differ in the direction of spin of the nuclei of the atoms forming the molecule. The equilibrium between the two forms is a function of temperature and in the liquid state a change results in heat production and a serious evaporation loss. The change can be acclerated by catalysts during the liquefaction cycle or the heat release can be countered by a refrigeration system in the storage tank. For large-scale production and storage the second option would seem to be of more value.

In the absence of an oxidizer, liquid hydrogen is quite stable; it should be a good coolant as it has a high heat capacity, and its extremely low density enables high linear flow rates to be achieved in the coolant passages for a comparatively small pressure drop. Also the initial temperature is low allowing a proportionately greater temperature rise in the coolant passing through the chamber without damage occurring. Its boiling point is very low, however, and large-scale storage presents hazards. It is necessary to exclude air as the gases solidify at liquid hydrogen temperatures and collect at the bottom of the tanks producing a very sensitive mixture. Also mixtures of the gas and air may be detonated and inflammability limits in air are very wide. At liquid hydrogen temperatures there are no corrosion problems; low temperature embrittlement of metals is a difficulty but materials are available for use, *e.g.*, stainless steel, monel, nickel, etc. The extremely low density of liquid hydrogen is a great disadvantage to its acceptance as a fuel. Liquid fluorine would appear to be the best oxidant to use with liquid hydrogen, as besides giving the highest performance figure, it has the highest density of the oxidants available, though the use of hydrogen with liquid oxygen may well have a bright future.

Considering the other elements more generally:—

Beryllium

Its ores are scarce and not easily worked and the metal is in great demand for the nuclear power programme. For these reasons it is not a practical proposition as a rocket fuel.

Lithium

It is fairly abundant on the Earth's surface where it occurs in proportions almost as great as zinc but there are few good ore deposits and extraction costs are high. It is used in the atomic power industry and might be produced in quantity; it is a possible fuel.

Boron, magnesium, aluminium and sodium are all fairly readily available and might be considered as rocket fuels.

Compounds

All these elements which might be used as fuels, apart from hydrogen, are solids. Sodium and lithium might be injected into the chamber in the molten state as they have relatively low melting points but this would appear to present a difficult engineering problem. Boron, magnesium, and aluminium would need to be used as slurries.

Methods have been devised so that slurries can be made easily, *e.g.*, slurries containing up to 60% by weight of magnesium have been reported. But the production of different batches of slurries with identical physical properties is difficult and as the life of a slurry depends on its physical properties, useful storage time may vary from batch to batch; from 4 weeks to 6 months are figures quoted for apparently identical batches. Temperature variations, contamination, etc., affect the stability and though the materials are easily pumped, the deposition of solids in the coolant channels of the rocket engine is a possibility. Also, if the element is used as a slurry, it is effectively diluted by the supporting fluid with a resultant lowering of performance.

All the metallic elements produce oxides which are solid at room temperatures; some are solid or nearly so at rocket reaction temperatures and may cause deposition on the inside of the chamber. Solid materials in the exhaust may also cause a loss in performance as all the heat contained in the solid may not be converted into kinetic energy in the expansion process.

Thus, apart from hydrogen the possible fuel elements have not shown up too well in the light of propellent requirements. There is, however, the possibility that some compounds of the elements, particularly the hydrides, might be useful propellents. Table III shows some of the hydrides available and some of their physical properties. Lithium borohydride, lithium aluminium hydride, lithium hydride and sodium and magnesium hydrides, etc., are solids and are therefore discounted. Aluminium hydride is a gas and aluminium borohydride is a liquid which is spontaneously inflammable in moist air. Both have the disadvantages that they produce sticky aluminium oxide with oxygen and have high reaction temperatures with fluorine. This leaves the boron hydrides, and introducing nitrogen and carbon into the list of elements, the nitrogen hydrides and the hydrocarbons. Nitrogen compounds, because

of the high stability of the nitrogen molecule and therefore the energy evolved on recombination of nitrogen atoms, make excellent explosives and propellents. The hydrocarbons to be considered are acetylenes and substituted acetylene compounds.

Boron occurs extensively in nature and large quantities of borax are extracted every year. Considering the hydrides; diborane is a gas and is toxic as are all the boron hydrides; tolerable working limits being about 1 p.p.m. in air. It reacts with air and moisture, hydrolysing very rapidly; it also decomposes on heating, giving tetraborane and hydrogen. When stored at room temperatures it gradually decomposes; after about 4 months 50–60% diborane is left. When heated in air it ignites at about 150° C. though it is not spontaneously inflammable; it also has wide inflammability limits in air and its flame speed is high giving a chance of detonation in air. Pentaborane is a liquid and is much more stable than diborane. It decomposes on heating, precipitating boron and evolving hydrogen; there is thus the possibility of blocking of coolant passages in the engine. It is spontaneously inflammable in air and may in certain circumstances detonate. Decaborane is a solid and quite stable in air. Substitution of methyl groups into the molecule, *i.e.*, the formation of methyldecaborane, results in a lowering of the melting point though the methyl group is effectively a diluent. All the boron hydrides are compatible with most materials of construction, though rubber is not with pentaborane. Performance with both fluorine and oxygen is good. The exhaust from all boron-fired rockets will be toxic and with fluorine as oxidant, chamber cooling difficulties are also envisaged; with oxygen, deposition of the oxide is possible.

Nitrogen also occurs widely in nature and both ammonia and hydrazine contain large amounts of fixed hydrogen and have fair performance figures. Ammonia has the disadvantage of a high vapour pressure which may make it difficult to use as a coolant and hydrazine is extremely sensitive and may detonate on heating. Certainly hydrazine will be much more difficult to use as a coolant than ammonia and a hydrazine rocket engine should contain no dead spaces in the coolant passages. Hydrazine also has a high melting point though this can be decreased by mixing with ammonia at the expense of increasing the vapour pressure and lowering the performance. Methyl groups can be used to decrease its freezing point, as we have seen above in the case of decaborane (Table III) and unsymmetrical di-methyl hydrazine has already found use as a rocket propellent. Ammonia is already produced in large quantities by the chemical industry but hydrazine is not yet believed to have been produced in bulk as the anhydrous material; its production costs in any case are likely to be high. In view of this and its sensitivity, it seems unlikely to be used as a general purpose propellent in the future.

Of the possible hydrocarbons, both acetylene and methylacetylene (propyne) have a high performance though the former is extremely sensitive and is readily detonated in the liquid form. For this reason, it is unlikely that liquid acetylene will ever be used as a rocket fuel. Addition of a methyl group to the acetylene molecule producing propyne, results in a more stable compound which can be produced in quantity and is easily handled. Other substituted acetylene compounds can be produced, all with varying performance figures and with different degrees of stability; of these materials, propyne would seem to be most likely to be used as a fuel.

[*Continued on page* 206

TABLE III.—*Physical properties of some of the boron hydrides and other hydrides*

Material	Physical state at normal temps.	Melting point °F.	Boiling point °F.	Specific gravity
Diborane B_2H_6	Gas	− 265·9	−135	0·21 (liq.)
Tetraborane B_4H_{10}	Liquid	− 184·0	64·4	0·56 (− 31° F.)
Pentaborane B_5H_9	Liquid	− 59·8	136·4	0·63 (61° F.)
Hexaborane B_6H_{10}	Liquid	− 85·2	—	—
Decaborane $B_{10}H_{14}$	Solid	209·7	415	0·98 (68° F.)
Aluminium borohydride	Liquid	− 83·5	112	0·544 (68° F.)
Beryllium borohydride	Solid	196·3	253·4	—
Dimethyl aluminium borohydride	Solid	57	—	—
Lithium borohydride	Solid	527	—	0·681 (68° F.)
Sodium borohydride	Solid	932	—	1·08
Magnesium borohydride	Solid	—	—	—
Zinc borohydride	Solid	—	—	—
Lithium hydride	Solid	1256	—	0·82 (68° F.)
Sodium hydride	Solid	—	—	—
Ammonia	Gas	− 108	− 28	0·66
Hydrazine	Liquid	35	236	1·00
Methyl hydrazine	Liquid	− 61	189	0·87
Dimethyl hydrazine	Liquid	16	176	0·82
Unsymmetrical dimethyl hydrazine	Liquid	− 61·6	145·4	0·78
Acetylene	Gas	− 119·2	−115·2	0·4 (− 4·5° F.)
Methyl acetylene (propyne)	Gas	− 152·9	− 9·8	0·645 (32° F.)

★ ★ ★ ★ ★ ★ ★ ★ ★ WITH GAGARIN

The photographs on these pages are taken from the Soviet colour documentary film, "With Gagarin to the Stars," which opened in London on 3rd September.

This rocket, used to simulate the launching of Vostok I, bears a strong resemblance to the Soviet T-1 tactical missile seen on many occasions in Red Square anniversary parades.

All pictures Warner-Pathe

This picture shows Major Gagarin's "space-helmet" to good effect. The transparent visor is open for most of the time, when the astronaut is breathing cabin air at normal atmospheric pressure.

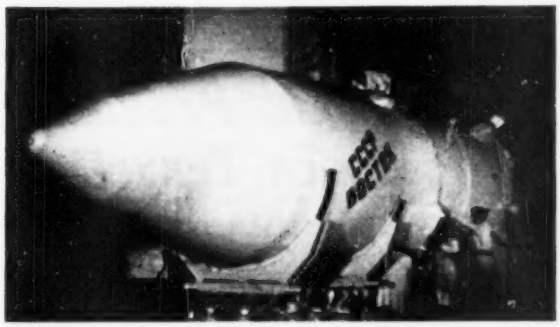
With electrodes attached to his head and body, Major Gagarin undergoes medical checks before his orbital mission.

All set for lift-off. Major Gagarin appears to hold switches, one of which may be for ejecting the couch from the spacecraft in emergency.

INTO ORBIT ★ ★ ★ ★ ★ ★ ★ ★ ★ ★

Mating the two sections of the Vostok spacecraft. The pressure capsule (forward) is the part which contains the astronaut. The aft section appears to bear some relationship to the final stages of the Lunik carrier rockets (*Spaceflight*, Vol. II, No. 6, p. 176).

Strelka and Belka, two of the animals which served as "path-finders" for Russia's man-in-space programme. They orbited the Earth in Spacecraft II more than 17 times on 12–13 August, 1960 and were successfully recovered.



The two components of Vostok are joined. Although not stated in the film, it appears that the rear section is jettisoned before the pressure capsule re-enters the atmosphere at the end of the mission.

Preparing Major Gagarin for his historic mission on 12 April, 1961.

Television pictures of Major Gagarin are relayed from Vostok to ground stations during the flight.

An array of food containing concentrated vitamins, proteins and carbohydrates, some of it in "squeezable" plastic tubes. The screw caps are tethered in case they come loose in the cabin under weightless conditions.

Continued from page 203

Oxidizers

Oxygen is already a familiar material in the engineering world; it is readily available and is used in large quantities for rocket propulsion. Ozone, its allotrope, provides a performance increase but so far as is known has not been produced in bulk and is extremely expensive. It seems less likely to be used as an oxidizer than fluorine due to its great sensitivity; it detonates violently with very little provocation though it is reported to be stable when extremely pure. It is also toxic. When mixed with oxygen at concentrations up to about 30% ozone it is definitely stable; above that concentration two phases are formed and there is risk of detonation. The 30:70 ozone/oxygen mixture would give an appreciable increase in performance with hydrogen combinations (Table I). An increase might also be expected for kerosene with this oxidant.

Fluorine is readily available from a number of chemical processes. It generally increases the performance of a rocket fuel, but in the case of hydrocarbons where the large, heavy molecule CF_4 is formed, the performance drops. For this reason fluorine/oxygen mixtures are used with hydrocarbons, the aim being to react the carbon with oxygen and the hydrogen with the fluorine. Unfortunately, fluorine also gives high reaction temperatures with fuels other than hydrogen; for this reason cooling difficulties must be envisaged.

Fluorine is difficult to handle; it reacts violently with traces of water and grease and most substances ignite spontaneously when subjected to concentrated blasts of the gas; pumping the liquid would appear to pose a very difficult problem. The gas and its salts are extremely poisonous and contamination of the skin with the liquid produces burns which, if at all severe, require surgical treatment. The liquid has a low boiling point and until recently was considered to be too hazardous a material to be stored although tank cars have recently been developed in the U.S.A. and the liquid can be delivered in bulk.

Care is required in the choice of materials of construction for use with fluorine; monel, nickel, copper, certain brasses, etc., being suitable. The effect of a leak of the liquid would be catastrophic; the exhaust from the rocket would be highly toxic. The liquid has a high density (S.G. = approx. 1·54) which indicates that it should have a good performance in the rocket. Obviously there are many problems in the use of liquid fluorine and much work is still required before it can be considered as a constituent of a "work horse" propellent combination.

Both fluorine/oxygen mixtures and ozone/oxygen mixtures present less pressing problems than the use of pure fluorine and pure ozone and are therefore worthy of consideration. F_2O, difluorine monoxide, is not considered worthy of consideration in view of its very high cost of production, toxicity, etc.

Conclusions

From the survey, it is seen that the use of metallic elements as slurry fuels in liquid fuel rocket engines is likely to be difficult and the dilution effect of the liquid supporting medium will reduce performance. Their use in solid propellents is more promising. Hydrogen, boron-hydrides, ammonia, hydrazine and the substituted hydrazines and acetylenic compounds are possible fuels with fluorine, ozone and oxygen and their mixtures as oxidizers.

Hydrogen is at first sight the best fuel but has the disadvantage of a very low density. Hydrazine is not considered a feasible fuel at the moment though unsymmetrical di-methyl hydrazine has been used in some large rockets and has a performance approaching that of hydrazine. Boron fuels have many disadvantages and are discounted at their present stage of development. The use of substituted acetylenic compounds, *e.g.*, propyne, with oxygen is possible. If hydrogen is to be used as a fuel, fluorine would appear to be the best oxidant though both ozone/oxygen mixture and oxygen are possibilities and a number of large engines to use hydrogen/oxygen propellent have been built in the U.S.A.

Some Legal Problems of Space Travel*

By J. M. SMAIL, LL.B.

In this paper I shall endeavour to provide some idea of the legal problems which currently affect the use of what is commonly called "space" and which I attempt to define as that portion of the Universe not temporarily occupied by the Earth or some other body.

This must be taken in a broad sense because, if current theories are true, space extends even into the make-up of the ultimate particles of more solid bodies. It is all-pervading, and this fact could raise some very interesting theoretical problems which I merely touth on in this address to you. One very interesting one derives from the problem as to whether the Earth drags its own space along with it as it does its atmosphere and if it does what happens to the hole in space it leaves behind. I shall endeavour not to obfuscate you with such problems, but will concentrate on the practical issues raised by the present state of opinion of international lawyers on problems actually facing us.

First and foremost of these problems, as you are, no doubt, aware, is the question of sovereignty over (if that is the correct preposition) what is known as the "airspace" above the territory of each political entity known as a national state. Upon the view adopted on this point, decisions on the other problems with

* *Lecture presented before the Sydney (Australia) Group of the British Interplanetary Society on 26th May*, 1961.

which I shall deal will depend. These other problems are: assuming air-space or the sovereignty thereof to have a limited range, what rules are we to adopt in relation to the navigation of or intrusion into space not the subject of such sovereignty; what rules are we to adopt in relation to either the landing on or possession of other celestial bodies; what rules are we to adopt in relation to telecommunications in non-national space? You will notice that I use the word "space" somewhat loosely, but I hope my meaning may be clear in each case.

I need hardly add that what I have set out by no means exhausts the list of items for consideration, but they appear to be the main matters which can conveniently be dealt with in a short talk.

The question of the extent and nature of the sovereignty of the territorial state has long been a central problem of international lawyers from Grotius on. Early views seem to have derived from the idea of "effective control" which appears to be the basis of the modern "3-mile limit" for sovereignty over territorial waters, this limit being assumed to be "three gun shots" from the shore. These early rules, up to the end of the nineteenth century at least, were for the most part based on the custom of civilized states, supplemented by international conventions or inter-state agreements. With the growth of air navigation in the twentieth century it became clear that the old rules could not be profitably extended.

There were two main theories of state sovereignty over airspace propounded. First, on the analogy of the freedom of the high seas, that the gaseous envelope surrounding the Earth was in the same position as the high seas and not capable of being the subject of sovereignty above a certain limit which could be defined on some such basis as "effective control." The second theory, basing itself on the old Roman law concept of property rights, held that a sovereign state had the right to control the space above its territory to an indefinite limit, *usque ad coelum*, as the Latin phrase had it. The difficulty in the latter view was in finding a suitable definition of "coelum," "heaven," as it was usually translated. Implicit in its use was that there was such a place as heaven.

This latter consideration is not unimportant when we consider that it was used in relation to a concept of the structure of the Universe involving concentric spheres, whereof the Earth was the centre, and the outermost sphere was "*coelum*," the abode of the Angels, the original extra-terrestrial flying objects! *Coelum* was also considered to be a good deal closer to the Earth than current views would allow to be possible.

Copernicus and his successors put an end to this conception of the Universe. Hence, it would appear that the original Latin phrase, for all its usefulness as a concept of private law for the limited purposes of everyday life, such as stopping your neighbour building balconies over your land, could no longer suffice as a definition of sovereignty to an unlimited degree. Consider for a start the problems arising from the Earth's proper motions if sovereignty were unlimited.

There are three commonly known motions of the Earth. They are, diurnal, annual and nutatory. I omit consideration of its motion about the common centre of gravity of the Moon and itself, together with its motions as part of the Solar System about the Galactic centre or its common galactic motion. It becomes quite clear how untenable the theory of unlimited sovereignty becomes when we consider that the part of the Universe which is immediately overhead at any one time is constantly changing and if the theory were pursued to its logical conclusion nearly every state could claim sovereignty over all the Universe. The recent Russian comment on the subject quoted in *The Sun* of 9 May, 1961, put the matter in a nutshell when it said that, far from infringing the national sovereignty of other nations, Major Gagarin's spaceship caused other nations to infringe Russia's sovereignty by revolving under the airspace occupied by Russia at the moment of launching. I do not for a moment imagine that he was speaking seriously of any Russian claim to sovereignty, but it does highlight the absurdity of any claim on unlimited sovereignty over airspace. Incidentally, this position was taken up as far back as 17 October, 1957, by G. Zadorozhnyi in an article in *Sovietskaya Russia*.

Equally, it would seem that a doctrine of unlimited freedom to navigate the airspace above a particular national territory based by analogy on the freedom of the high seas would not be agreed to by the nations even if it could be said that there was a complete analogy between the ocean of water and the ocean of air. In fact, the one thing that all nations represented at the 1910 Paris Conference seemed not to dispute was that they had sovereignty over the airspace above their respective territories, and this view was embodied in the Paris Convention of 1919 and the current Chicago Convention on International Civil Aviation of 1944, adopted in Australia by section 3A of the *Commonwealth Air Navigation Act*, 1920–50, which came into force 30 April, 1947. It is to be noted that by both these Conventions the signatories agree that they recognize the sovereignty of non-signatories over their own airspace. The U.S.S.R. has not acceded to this Convention, but it claims sovereignty over its own airspace by its own law. As a result, it can be taken that all nations recognize that each sovereign nation has the right to control its own airspace.

This, however, leaves the question still undecided what is "airspace" for the purposes of international law.

There are three main suggestions put forward. The first, which stems from the old theory of effective control, postulates that the airspace should be that portion of the atmospheric envelope in which an aircraft can derive support from the air. There are certain difficulties involved in this view, among them determining just how thin the atmosphere has to be for this purpose, particularly in view of modern advances in speed and aircraft design. In some ways this is a useful concept and it

should not be beyond the bounds of posssibility that a height could be fixed on this principle for practical purposes. However, from the control point of view it seems quite clear that craft depending on exhaust velocity for propulsion and which are not dependent upon the atmosphere for support are just over the horizon if not actually in use. As variants on this scheme the mean effective height of anti-aircraft fire has been suggested. Again, in view of the development of guided missiles and similar anti-aircraft apparatus, there would be difficulty in fixing what is mean effective height. It is to be noted in this regard that the Chicago Convention left the definition of aircraft flexible, although agreeing, as a temporary measure, it would include aircraft deriving support from the atmosphere.

The second limit proposed is the point where the atmosphere surrounding the Earth merges into the tenuous gaseous matter which is presumed to pervade all space. Sixty thousand miles seems to be a reasonable limit for this purpose and, if the matter were still at large, no doubt could have been fixed as a limit. However, as so often in these cases, events have taken the matter out of the hands of the legislators. In fact, both the United States and the U.S.S.R. are launching satellites into orbit without protest from anyone, and these satellites do not have apogees much beyond 1000 miles, while their perigees are as low as 90 miles or so. It seems quite clear that this is not a practicable proposition, although I shall return to the question indirectly again.

The third solution is to fix a point where the gravitational field of the Earth would cease to exercise any control over a free-falling body in relation to the field of the Sun. This has much the same practical objections as the last-mentioned suggestion, particularly as this point is even further away, about 161,000 miles to be exact.

Returning now to the question of the actual practice of nations, it must be emphasized that international law as such is based on the practice of nations. However, Michael Aaronson, an English barrister who wrote in the *B.I.S. Journal*, has pointed out that the international law of air navigation has, in the twentieth century, been the creation of express agreement and adumbrates that this is the manner in which such law must develop in relation to the use of what I shall term Outer Space. I myself am unable to agree with this point of view, for the simple reason that the various satellite programmes of the two nations most deeply concerned have involved a practice, which has passed now sufficiently often without protest as to have achieved the status of a right, to project satellites into orbit. The Russian point of view is quite specific that, certainly in so far as orbiting satellites are concerned, much the same principles apply as do those on the high seas. As a concomitant, they obviously must claim the right to project such satellites into orbit at least through their own atmosphere. The United States apparently claims this right to the extent of being allowed to do so through the Cuban airspace—or, at least, the right of free passage for bits of their destroyed rockets on their way to the ground!

The fact of the matter is that just as the modern law of the navigation of the high seas developed under the stimulus of the practice of the nations most deeply involved in such navigation, and particularly under the pervading fact of British command of the seas, so it is not impossible that, if developments go the way they appear to be doing, Russian practice will determine largely the details of the rules of international law as applied to Outer Space. This does not mean that I necessarily believe that this is what will happen: I have too much respect for American energy and ability to imagine that they will not make tremendous efforts to catch up any leeway there may be, and we may yet have the spectacle of a period of freebooting in space comparable to the Elizabethan privateering.

To summarize the position as it stands at the moment, it appears that each national state has the right to control its "airspace," however defined, to a limited height, determined at the moment by the height at which ordinary commercial or military aircraft can fly. This much was determined by the case of the U-2, where America did not protest at the trial of its navigating pilot by the Russians. It may not be unimportant, however, to add that President Eisenhower did in several semi-official speeches claim indirectly the right to send observing aircraft over a nation which would not allow other nations freely to inspect their territory or which kept their military installations a close secret.

It would also appear to be established that any nation has the right to project what we shall call "satellites" into orbit around the Earth at least through their own airspace and, possibly, without causing damage, through the airspace of other nations. As a corollary, one must accept that such satellites, if equipped with observing apparatus such as high-powered telescopes and telemetring equipment, would not infringe this rule. The U.S. weather satellites establish this. Nobody apparently objects to any nation taking photographs of the other side of the Moon!

Just where we are to draw the line between the first conception and the second is difficult to say and, no doubt, will have to be worked out as reaction craft fly higher and higher and satellites perigee lower and lower.

Before leaving this aspect I would like to point out that the Earth's gaseous envelope is dragged through space with the Earth, and it might be possible to fix "airspace" at some reasonable height involving only such of the Earth's atmosphere as is dragged with it in its proper motions. This, in practice, would involve fixing a height, and this is what ultimately seems to be involved as a result of current practice Again, the height thus proposed may be too high.

If my view of the position is correct, the matter does not end there. Two immediately practical problems are the evolution of a code of practice for space navigation analogous to the Rules of the Road at Sea, and the

general international regulations agreed on for the purpose of enabling all those entitled to make reasonable use of the high seas and contiguous ports or analogous to present international air navigation rules. Among the more important details would be: use of "space-ports," damage by matter falling from satellites or passing spaceships upon territory other than that of their own sovereign state and, by extension, damage to private persons by similar activities of either foreign or own national spaceships. To this would be added certain problems arising out of the repatriation of astronauts forced down in foreign territory and their internment.

Before passing to the final chapter of this talk, which will deal with the right to acquire and possess other celestial bodies or parts thereof, it may be as well to consider briefly the implications of some other matters arising out of the increased use of satellites.

One of the first problems will be that of the allocation of radio frequencies for use by satellites and spaceships. This should present no more difficulty than the present provisions relating to telecommunications. Just how far any nation or individual would have the right to appropriate the picture relayed from a satellite, assuming he could construct an apparatus capable of displaying it, is problematical, but on the analogy of television it is difficult to see how he could be prevented from viewing or discussing what he had seen. Making a permanent record may be another matter. There will obviously have to be a lot of *ad hoc* legislation before a coherent code can be worked out. Similar considerations apply to T.V. or other relay satellites in fixing positions. How far are other nations entitled to make use of them as reflectors? Of course a lot would depend on the possibility of proving that there was deliberate interference or use as against fortuitous use. There was, apparently, some radio interference by the first Sputnik. How far can this be tolerated on a large scale, however much we may be prepared to put up with the relatively minor interference up to date?

I have only propounded the above for the purposes of indicating the scope of the problems confronting us before we leave the Earth, or before we leave its immediate vicinity. I will close this talk with a few remarks concerning the problems we are likely to come up against in exploring beyond the immediate vicinity of the Earth.

Our nearest neighbour is, as is well known, the Moon, and our first problems are likely to arise in connection with landing on the Moon. I disregard claims which may be preferred by those who first land such apparatus as "probes" and unmanned vehicles and the rather shaky titles of those selling real estate on the Moon. The more difficult question will arise when there is an actual physical landing—if we can refer to "landings" on the Moon. It seems fairly clear that on the Moon we are not likely to be confronted by indignant races of Moon-men (or women!) resenting our intrusion, so that the problems which arise will be those arising out of effective occupation.

The main contenders in the space race have each made pronouncements that the exploration of Outer Space should be conducted under international auspices free from territorial claims, but, however sincere these pronouncements may be, the practical problem of securing such co-operation is so obvious as to need little elaboration. It may be possible to demarcate zones, as is done at the present time in the Antarctic, for the exploration of the Moon's surface, but this will undoubtedly not be practical politics until at least two nations have permanent or semi-permanent stations on the Moon's surface. My own view is that the first nation on the Moon will undoubtedly set up wide claims, such as those of Australia to the Antarctic. It will be difficult to dispute these in fact until some other nation lands there. After that, no doubt, the doctrine of effective occupation, which is recognized by the U.S. in regard to the Earth's surface and is probably recognized by the U.S.S.R., will come to be the recognized doctrine. Clashes are inevitable and it is to be hoped that they remain verbal and that the rivalries of Earth are not transplanted in an acute form to the rest of the Solar System. As regards the legal position, however, it cannot be said that there is any consistent body of opinion on the matter at the moment. Effective occupation seems to be the most likely contender.

The remaining matter to be considered is: what if the other celestial bodies are inhabited? I do not propose to devote much time to this as the possibilities are remote and will have to be left to the future. It would seem, nevertheless, that Haley's principles of "No Injury" and "Invitation" ought to be applied in a modified form. That is to say, we should do everything in our power not to bring harm to any of the inhabitants of such celestial spheres as may be inhabited by rational beings, and that in so far as possible, if it is clear that a celestial body is inhabited by rational beings, wait for some clear invitation to land to be given and landing places designated before any descent on to the surface is made. It is again sincerely to be hoped that man's trail into the heavens is not to be marked by the past injustices accompanying the incursion of alien races into other people's territories. I am not confining myself to the expansion of Western nations in this regard, for all relatively advanced nations are at fault in this matter. The Australian Aborigines expelling the Tasmanians, the Maoris the Moriori, the Malays the Sakai, the Aryans the Dravidians, the Bantu the Hottentots, and ourselves the Aborigines. I only hope, as I said, that these mistakes will not be repeated. My studies of history do not lead me to believe that they will not.

NOTE: *In discussion it was suggested that any height fixed should be measured from the centre of the Earth radially rather than from the Earth's surface and that practical problems of observations to determine whether trespass into airspace had occurred might be limiting factors as regards the sovereignty over airspace.*

Unchanging Moon?

By JOHN W. MACVEY, F.R.A.S.

T. W. Rackham

As many of the names of lunar formations and features would suggest there was a time when the Moon was regarded as a world not greatly dissimilar to our own. Such terms as seas, oceans, bays, etc., so freely given, bear eloquent testimony to this period. However, as optical powers increased and methods of physical measurement were developed, the belief that our satellite was in fact a stark and most forbidding world came rightly into increasing vogue. Today no one would seriously suggest that the picture as now presented is essentially other than fundamentally correct. Nevertheless, over the years of the last century certain peculiar changes have been reported which might seem to indicate that the surface of the Moon is not cast in quite the same unchanging mould as some have believed.

From a point some quarter of a million miles distant it is far from easy to do much more than guess at the reasons for most of these alleged changes and it would seem that for confirmation and explanation the astronomer with his telescope must perforce turn to the astronaut with his spaceship. Such investigations by the latter might not only cover those features which have reputedly shown change, but also a few for which a valid explanation of origin is not easily forthcoming. With the advent of manned descent on the Moon now surely only a matter of some years distant, such a subject becomes of increasing interest and full of unique possibilities.

It may be desirable, therefore, to dwell (of necessity somewhat briefly) on some of the principal changes which are reputed to have taken place on the surface of the Moon within fairly recent times, and which on account of their enigmatic nature could perhaps be more adequately investigated and rationally explained by a lunar expedition. It seems fairly logical to assume, therefore, once lunar bases have been firmly established and general lunar conditions studied, that Moon-based selenological expeditions may well give some measure of priority to the investigation of these perplexing phenomena which would appear to have taken place on a "dead" and allegedly unchanging world.

Linné (Linnaeus)

This crater located on the Mare Serenitatis provides one of the classical instances of a change having taken

place on the surface of the Moon. It stands out against the darkish background as a small whitish spot which, by virtue of its lack of height, casts no perceptible shadow. In 1843, however, Schmidt reported Linné as being a crater some 6 miles in diameter, with an estimated depth of 1200 ft. In fact he and several other contemporary observers made practical use of it as a reference point on the otherwise smooth surface of the "mare." Almost certainly Linné would not be so used today. Any possibility of locational error would seem to be ruled out since the position of the white spot now coincides with that given in 1843. The most recent reports on Linné indicate a central craterlet in a bright patch *plus* a slightly smaller *second* object attached to its south wall.[1,2] There would even seem to be a possibility that a *third* small crater exists.[3]

Alhazen (the original)

The case of this crater is somewhat familiar to that of Linné. It stands on the western border of the Mare Crisium and had a diameter as estimated by Schroter of some 23 miles. It too found use as a reference point and so must also presumably have been a fairly conspicuous object. By the time of Mädler, however, it also had largely vanished leaving in its place merely a minor depression between two peaks. As a result of its now insignificant character and dimensions, Mädler transferred the name to another crater some way to the south.

In both the cases of Linné and the former Alhazen some form of seismic disturbance seems the most likely explanation. One might even be tempted to use the term "moonquake"!

Plato

Lunar sunrise over this particular crater is very much like sunrise over any of the others. The ringwalls cast long shadows which become progressively shorter as the Sun climbs steadily higher in the lunar sky. With most craters this is the inalienable pattern leading eventually to a flat virtually shadowless effect from which it is much less easy to pick out detailed features. In the case of Plato, however, there is a remarkable difference. As the terminator (demarcation line between light and darkness) advances, the floor of Plato becomes not *lighter* but *darker* until at full lunar noon it is intensely black. Several theories have been advanced to explain this rather remarkable incongruity though it must be admitted that none of them seems particularly plausible.[4] These are as follows:—

(i) the evaporation of moisture to form a light absorbing mist;

(ii) the presence of melting ice;

(iii) the existence of crystals with rather freakish optical properties.

The first two by implication demand the presence of water in some form or another. From what is known of the Moon this seems at best improbable. The third, if it is to be seriously entertained, requires the granting of a certain amount of licence in the fields of chemistry and crystallography!

Many modern observers today, such as Haas, have contradicted these earlier assertions regarding Plato. Yet it seems improbable that all these older observers could be mistaken. Far from being a minor feature about which some dubiety might have been expected, Plato is, in fact, a particularly conspicuous one. In all fairness it is equally unlikely that all the modern observers are wrong, and consequently one feels tempted to suppose that some form of change may indeed have occurred. It is also appropriate to mention that several experienced and reliable lunar observers attribute the darkness to obscurations caused by local features[5]—a situation not wholly unknown on the lunar surface. This seems considerably more plausible than some of the other explanations. Nevertheless, the case of Plato remains an interesting and intriguing one.

Eratosthnes

This is a typical rather beautiful crater some 38 miles in diameter with a depth of over 16,000 ft., in which the famous Lunar observer, Pickering, repeatedly reported the existence of greyish spots in motion. The degree of reliability to be accorded to this may well be a moot point! Nevertheless in any such discussion it seems worthy of mention. Once again in quest of an answer the presence of water—this time in the form of clouds—was suggested. Another theory attributed the phenomenon to lunar vegetation springing up and then being rapidly killed off by the heat of the Sun.[4] Gas or vapours emanating from some deep fissure would seem a rather more logical and rational explanation. Pickering himself produced an incredible hypothesis involving masses of migrating lunar insects!

Werner

This particular instance involves one of twin craters, some 50 miles across, outside the western wall of Regiomontanus. Near the base of the inner north-east wall, Beer and Mädler reported the presence of a bright spot which according to them rivalled in brilliancy the famous crater Aristarchus. Today it is much less brilliant, and, whatever the reason it has certainly faded markedly during the passing of the last century.

Petavius

This is a large crater on the borders of the Mare Foecunditatus in which many reliable observers in the past reported a distinctly blackish area on the floor. Today this cannot be traced.

Messier and Pickering

Though described by Beer and Mädler as being almost exactly alike, today these two craters could hardly merit this description, for the latter is not only

deeper but considerably more distinct. This is, however, a case where the evidence is none too reliable since both craters display variations each lunation, a factor which can probably be attributed to the changing illumination.[5] In addition to this aspect, there is a further probable mystery concerning Messier since it has been described by Klein on some occasions as being seemingly "full of mist." Here again, if this is so, the possibility of some sublunar vapour escaping might profitably be considered.

Alphonsus

This is a prominent crater over eighty miles in diameter near the centre of the Moon's disc, which has provided one of the most recent examples of some kind of activity taking place on the surface of our satellite.

During the night of 3/4 November, 1958, while using the 50-in. reflector of the Crimean Astrophysical Society, Kozirev noticed that the crater's central peak was seemingly enveloped by a slowly moving reddish cloud, a phenomenon which persisted for approximately 30 min. Indisputable evidence of gaseous emission was shown spectrographically, implying a fairly considerable temperature rise. In short, the entire manifestation bore a very marked resemblance to some form of volcanic activity.[6] Quite soon conditions reverted more or less to normal, though several observers reported definite after-effects, notably the existence of a small reddish area on the southern slope of the central peak. One or two more on the other hand were unable to confirm this. It is not to be inferred, however, that this patch represented an area at high temperature, and a rational explanation might very well be that it was due to material ejected during the outbreak.

The entire phenomenon tends to give a rather interesting slant to the question of crater formation—meteoric theory *vis-à-vis* igneous theory, inasmuch that it tends to lend some support for the latter.[5,7] It is also worthy of note that in the months prior to this phenomenon several transitory obscurations had been suspected in this vicinity.[8]

Hyginus N

This particular feature cannot be classified as a crater and is more in the nature of a depression approximately 3 miles in diameter. It was first reported by Klein in 1877. Oddly enough this same observer had scrutinized the region for about a dozen years prior to this without spotting it. Neither was it shown on any lunar map up to this time, with the result that Klein felt safe to conclude that the feature was new. The same region had also been extensively and repeatedly drawn by Schmidt during the preceeding quarter century, and it is interesting to note that in the same position he had at times recorded a bright spot, at others a dark one and quite frequently nothing at all. From this evidence he too concluded that a change had taken place.

Several other instances might be added to those already quoted, some of dubious validity, others with more claim to serious consideration. But perhaps these few may serve to indicate that the first voyagers to the Moon may well have a few surprises in store.

REFERENCES

1. G. P. Kuiper, Photographic Lunar Atlas.
2. D. Alter, *Publications of the Astronomical Society of the Pacific*, **70**, 490.
3. ——, *Journal of the British Astronomical Assoc.*, **71**, 1, 36.
4. W. Ley, "Conquest of Space."
5. P. Moore, "Guide to the Moon."
6. Z. Kopal, *New Scientist*, 4, 1362.
7. J. W. Macvey, *Spaceflight*, **3**, 1, 13.
8. D. Alter, *Publications of the Astronomical Society of the Pacific*, **69**, 158.

A Super Echo

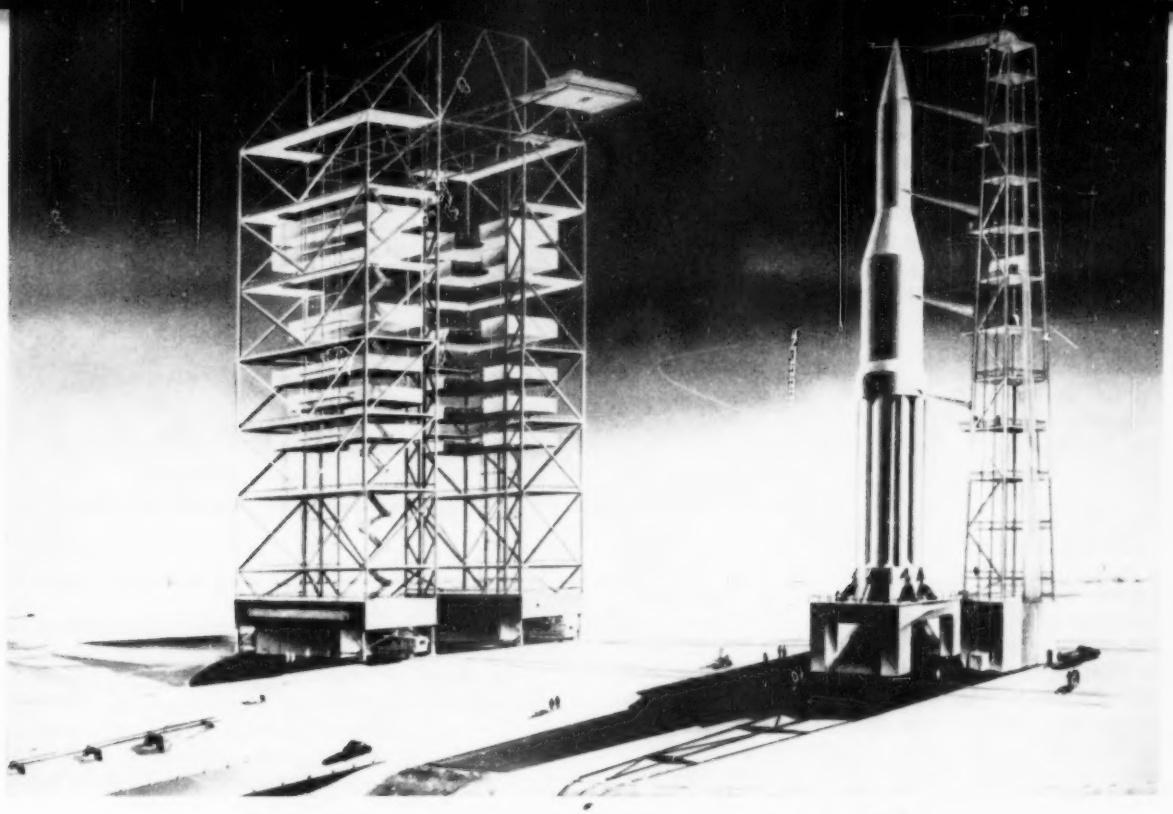
The National Aeronautics and Space Administration has negotiated a contract with the G. T. Schjeldahl Company of Northfield, Minnesota, for the design, development, fabrication and testing of "rigidized" inflatable spheres for its passive communication satellite programme, Project Echo.

The contract for approximately $400,000 will be managed by N.A.S.A.'S Langley Research Centre, Langley Field, Va., under the direction of the Goddard Space Flight Centre, Greenbelt, Maryland, the N.A.S.A. installation responsible for the communication satellite programme. Schjeldahl fabricated the Echo I satellite for N.A.S.A.

The spheres are to be fabricated of laminated aluminium foil 0·002-in. thick on each side of a layer of Mylar plastic 0·00035-in. thick. Each rigidized sphere will be 135 ft. in diameter and weigh approximately 500 lb. Unlike the lighter weight, 136-lb., 100-ft. diameter Echo I satellite, in orbit since 12 August, 1960, the heavier rigid structure is expected to remain spherical without internal pressure.

For maintaining thermal balance of the sphere within electronic operating conditions when orbiting in direct sunlight, the satellite "skin" will have a thin, uniform coating of black paint on the inside and a dotted coating of white on the outside. The white surface will reflect excessive heat, while the black inner surface will distribute heat to maintain uniformity in temperature throughout the satellite's interior.

Sub-orbital tests of the ejection and inflating mechanism of the rigid spheres will be made from the Atlantic Missile Range using a Thor rocket. The first rigidized Echo passive communication satellite will be launched into a 700-mile orbit from the Pacific Missile Range using a Thor Agena B vehicle during 1962.



Saturn Launch Complex 34

Construction has been completed of a massive rocket launching site at Cape Canaveral from which early Saturn space vehicles will be fired. It is the largest known rocket launching site in the world, and the first such base built especially for the peaceful exploration of space.

From this site the first Saturn heavy space vehicle will be fired in an experimental flight to test the booster propulsion system later this year. This will be the beginning of a series of large rocket test flights which is expected to lead, by 1965, to the launching of tons of instruments to the Moon and Mars, and early versions of the three-man Apollo spacecraft which will ultimately be used for manned lunar landings.

The facility, known technically as Launch Complex 34, was handed over to the National Aeronautics and Space Administration by the Army Corps of Engineers on 5 June. Although unintended, the word "Complex" is a fortunate name for the facility. It is both complex, and big, comprising:—

(*a*) a 45-acre installation, dominated by a movable servicing gantry 310 ft. high and containing 2800 tons of steel;

(*b*) a blockhouse with walls 12 ft. thick, having a steel door 2 ft. thick which weighs 23 tons;

(*c*) efficient fuel and liquid oxygen storage facilities which are capable of pumping 750,000 lb. of fluid into the big booster in less than an hour;

(*d*) a launching pedestal foundation reinforced by 4400 cu. yd. of concrete and 580 tons of steel;

(*e*) a total of 100 million lb. of concrete used in construction; and

(*f*) a unique automatic ground control station, a room 38 by 215 ft. long, located beneath the concrete and steel launching pad.

Test Procedure

When the first Saturn boosters arrive at Cape Canaveral, they will be taken directly to launch Complex 34 where they will be erected vertically on the launch pedestal in preparation for the mating with upper stages. Each rocket will spend several weeks at the complex until a long series of check-outs and verifications has been completed. Unlike many smaller rockets, these initial pre-flight tests will be made entirely at the launch area, instead of in a nearby hanger; the latter will be constructed in the near future to support later Saturn vehicles.

The Saturn C-1 vehicle, to be launched from this complex, will be a two- and sometimes three-stage rocket. Depending on the mission, it will measure 21½ ft. at the base and stand some 160 ft. high. The lift-off weight will be about 1 million lb. The booster, or first stage, will develop 1·5 million lb. of thrust, about four times greater than any vehicle yet fired by the U.S. A second-generation rocket—the Saturn C-2—will

have considerably more power and will be able to more than double the 20,000-lb. Earth-orbital capability of the C-1. Some later C-1's and the C-2 will be launched from another launch Complex (37), located nearby, which is now in the initial phases of construction.

Salient features of the major elements of launch Complex 34 are as follows:—

Servicing gantry. This is 310 ft. tall and has twin legs measuring 70 by 37 ft. wide at the base. The centre opening, in which the rocket will be situated during check-out, is 56 ft. wide; each of the legs contains a two-floor building which houses the structure's operating equipment and rocket check-out apparatus. The structure weighs 2800 tons, 1700 tons of which is steel. Cost of the tower was about $4,000,000.

The structure provides a means of erecting the rocket on the launch pedestal. It has a bridge crane of 60-ton capacity, with two individually-operated hooks having capacities of 60 and 40 tons. For checking out and servicing the rocket, the structure has a work deck at the 27-ft. level (at the base of the booster) plus seven fixed platforms at various elevations. There are also five movable, horizontally-retracting, platforms which can be adjusted to embrace the vehicle at any desired level.

Described as the world's largest movable wheeled structure, the tower is mounted on two pairs of standard-guage railway tracks. There are four carriages, each with twelve 36-in. diameter wheels. Four 100 horse-power motors which drive the carriages are powered by a 400 kW. diesel generator installed in the structure. The tower can be controlled by a single operator, situated in a cab at the 27-ft. level. It is capable of moving from 1½ to 40 ft./min.

Supporting the parallel sets of rails are two mammoth steel beams, 8 ft. deep, 10 ft. wide and 538 ft. long. The entire launch pad and service structure area was compacted to a depth of 28 ft. by the "vibro-floatation" technique. Nearly 7000 cu. yd. of hardcore material was used; the result was a relative density of 80% in the foundation area.

The Saturn launch pedestal of Complex 34 nearing completion.
National Aeronautics and Space Administration

The nearly completed blockhouse.
National Aeronautics and Space Administration

After check-out of the rocket is completed, the service structure will be moved to a paved parking area—the position it occupies at launch—some 600 ft. away. During movement, a hydraulically-operated beam between the carriages and the tower support points equalizes the load among the carriages precisely. The hydraulic cylinders are then used to jack the tower up to effect the tie-down or anchor arrangement; the 2800-ton structure is lifted 2 in. The tower is anchored at steel piers by huge wedges, hydraulically driven, to enable it to withstand hurricane winds of up to 125 m.p.h.

Control building. The Saturn control building is very similar to the blockhouses built at Canaveral for Titan and Atlas missiles. It has 12,500 ft. of protected floor space on two levels, and an additional 2150 sq. ft. of unprotected space in an equipment room which will not be occupied during launchings. It is a circular, domed building 156 ft. in diameter, with the ceiling 26 ft. from the floor. The inner dome, or "igloo," is of reinforced concrete, 5 ft. thick.

On top of this is an earth-fill which varies from 7 ft. in the centre to 14 ft. at the edges. The final layer is 4 in. of gunned concrete. For blast deflection purposes, there is a slope of 35 degrees from the top. The main entrance door, of steel and concrete, weighs 23 tons. The building is designed to withstand 311,000 lb. of pressure per sq. ft. There are two alternative means of emergency exit—42-in. concrete pipes, whose primary purpose is for air intake. The pipes terminate in a shed 300 ft. from the building.

The first floor of the building is to be used by booster and upper stages contractor personnel involved in tracking and telemetry operations. Technical and building utilities, rest rooms, etc., are also located there.

On the second floor, the main firing operation will be conducted. Equipment includes firing console, test supervision and conductor consoles and various monitoring

and recording panels. A small observation room is separated by glass from the operating area. Pre-launch activities in the area can be viewed from an observation balcony on top of the control building.

Launch pad. This is 320 ft. in diameter. It is constructed of reinforced concrete 8 in. thick. As indicated earlier, special foundations have been provided for the service structure and the launch pedestal, the two areas of the pad where there is great stress. In the vicinity of the flame deflector, the pad is paved with refractory brick to protect it from heat. The pad has a perimeter flume for taking away surface water, and possible propellent spillage.

Pedestal. In the centre of the launch pad is the pedestal from which the Saturn will be fired. It is a structure 42 ft. square and 27 ft. high. The pedestal foundation contains 4400 cu. yd. of concrete and 580 tons of steel. The foundation is 160 by 106 ft., with depth varying from 8 ft. at the centre to 4 ft. at the edges. The top of this foundation is 9½ ft. below the surface of the pad. The earth-fill between the foundation and the surface of the pad allows for the passage of various services, *e.g.*, high pressure gas and fuel lines.

Rising from the foundation and extending to 27 ft. about the pad are four concrete and steel columns, 7ft. and 4 in. square. To these columns are attached the bearing ring and anchor bolts for the rocket support arms. The columns are protected from the rocket's blast by insulated steel line plates.

Bolted to the ring at the top of the pedestal are eight arms. Four of these are used solely to support the weight of the rocket, while the other four both support the rocket and restrain it from lift-off until the proper burning condition has been achieved by all eight Saturn engines. These arms are fabricated of steel and are automatically controlled during the launch sequence.

Deflector. Beneath the launch pedestal is a rail-mounted flame deflector. This 120,000-lb. steel structure diverts the 5000° F. jet stream in two, opposite horizontal directions. The deflector is 20 ft. high and 50 ft. long; the deflection angle beneath the engines is 60 degrees. When not in use, the deflector is parked on rails away from the pedestal. A spare deflector is parked on the opposite side of the pedestal.

Umbilical tower. Adjacent to the launch pedestal is the umbilical tower, the main function of which is to provide electrical and pneumatic lines to the rocket. At present the Complex 34 tower is only 27 ft. tall. It will be increased in height as live upper stages are added to the rocket. The tower is 24 ft. square at the base. (It can be increased to about 275 ft. in height.) There is a steel bridge and a cableway connecting the umbilical tower to the launch pedestal.

Automatic ground control station. There is a room, known as the automatic ground control station, immediately beneath a major portion of the launching pad. It extends from the west edge of the pad eastward toward the control building, avoiding the launch pedestal area. The room is 215 ft. long and 38 ft. wide; ceiling height is 9 ft. It serves as a distribution point for all measuring and check-out equipment, power, and high-pressure gas. Included is a generator room which provides D.C. and A.C. power. The room is not occupied during launching.

A tunnel for personnel, and for passage of a dozen racks of cables, extends from the automatic ground control station to the other side of the pad. The cables are then fed into a roofed cableway which leads to the control building.

Fuel system. RP-1 fuel (kerosene) is supplied to the booster from two above-ground tanks located about 950 ft. from the launch pedestal. The tanks are 15 ft.

frontiers of the future

Following the opening of the space era, FLIGHT was first to introduce a regular special section—"Missiles and Spaceflight". As developments come ever faster, FLIGHT maintains the most comprehensive and detailed weekly news coverage, supported by many illustrations, authoritative features, accurate cutaway drawings, and translations from Russian sources. For the fullest reports of space progress, read FLIGHT.

FLIGHT

Thursdays 1s. 6d.

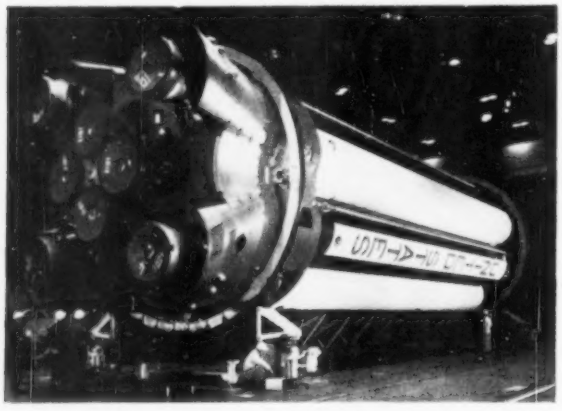
in diameter and have a capacity of 30,000 gal. each. A retaining wall is provided, along with revetments to retain the fuel should a tank rupture. An 8-in. fuel line leads to the rocket. There are two 1000 gal./min. pumps. Fuel is brought into the facility by truck transporters, three of which can unload at the same time. Unlike many other fuelling operations, this one is completely automatic, being operated from the control building fuel loading panels. Normally, the booster will be fuelled in about 40 min., although it could be accomplished in about half that time.

A facility for liquid hydrogen, the high-energy fuel to be used in Saturn upper stage, is to be ready by the time the live upper stages are phased into the programme.

Liquid oxygen system. There are two liquid oxygen (LOX) storage tanks some 650 ft. from the launch pedestal, well removed from the fuel facility. The main vessel is an above-ground sphere, with an outside diameter of 43 ft. The tank is surrounded by 4 ft. of "perlite" a mineral insulating powder, which controls the evaporation loss of less than half of 1% per day. An earth revetment protects the LOX facility on the side of the launch area. A 6-in. line feeds the rocket, at a flow rate of up to 2500 gal./min. Normally about 40 min. will be required to fill the Saturn booster's five LOX tanks, which hold an estimated seven tank cars loads. It can be done in much less time. The main LOX container operates under about 20 lb./sq. in.

A small liquid oxygen tank is used for replenishing the oxygen which boils off during the latter stages of launch preparation. It is a 13,000-gal. capacity tank, 12 ft. in diameter by 25 ft. in length, located near the main tank. Vacuum insulation assures the same low evaporation loss. A 3-in. line, under 200 lb./sq. in., leads to the booster.

The same LOX facility will be used in providing oxidizer for the upper stages of Saturn later in the programme.



The first "flight-weight" Saturn booster pictured at the Marshall Space Flight Centre before its 2,200-mile journey—mostly by barge—to Cape Canaveral.

Marshall Space Flight Centre

High pressure gas facility. There are several uses of gaseous nitrogen and helium in the preparation and firing of the Saturn. A high pressure gas facility is located about 1100 ft. from the launch pad and 200 ft. from the control building.

There are thirty-six 15½ cu. ft. (water volume) storage vessels divided into two groups. Four vessels contain helium used for bubbling the LOX tanks of the booster to keep the LOX from forming strata of different temperatures. Thirty-two tanks contain nitrogen which is used for purging fuel and LOX lines, engine and instrument compartments, for air bearings and for certain pressure-operated components such as valves. All of these tanks operate at 6000 lb./sq. in.

Other equipment includes two helium booster compressor units, which take helium from trailers and boosts it to the desired pressure level; there are also two trailer-mounted converters to change liquid nitrogen to gaseous nitrogen, each having a 1000 gal. storage capacity. A total of seven double extra heavy steel lines carry the gases to the launch pad; they vary in size from 2½ to 1¼ in. All gas distribution is made from the automatic ground control station, remotely operated from the control building.

An additional gas facility is planned, adjacent to the launch pad, which will provide 600 cu. ft. storage capacity for gaseous helium, to be used for pressurizing booster LOX tanks. There will be a total of twenty-seven vessels, 16 in. by 23 ft.

Skimming basin. A skimming basin is located about 300 ft. from the edge of the pad on the beach side. This is a paved vat 104 by 180 ft., which is used for the separation of water and fuel resulting from spillage, or from unloading booster fuel.

Water system. A water system has been installed on the pad and throughout the service structure, primarily as a safety measure. Water is available at all work levels on the tower for fire protection. There is a "pad flush" system to wash away spilled fuel. At the launch pedestal there is a quenching system for use in case fire occurs accidentally in the "boat-tail" or engine compartment. This system is also used to prevent backflame from entering the engine compartment in case the engines are cut-off immediately after ignition and before lift-off. Four 3500 gal/min. nozzles are being installed at the pad surrounding the rocket at about 100 ft. distance, as a general fire protection measure.

Operating support building. On the opposite side of the control building from the launch area, an operations support building is under construction. This building contains about 30,000 sq. ft. of floor space, and will be used for general shop and engineering activities, and spare parts storage.

Communication system. A voice communications system is being installed by the launch operations directorate. The system is designed for clear, reliable voice transmission regardless of high noise environment. The system will consist of up to 200 stations scattered throughout the 45-acre installation.

Reviews

"Atlas of the Other Side of the Moon." Editors: N. P. Barabashov, A. A. Mikhailov, Yu. N. Lipskiy. Pergamon Press, Ltd., London, New York, Oxford, Paris. 1961. 171 pp. with diagrams and photographs. Price 50s.

On 4 October, 1959, the Russians successfully launched Lunik III which accomplished the first un-manned circumnavigation of the Moon. Equipped with a complex set of scientific instruments, including photographic and television cameras, Lunik III photographed the lunar surface invisible to terrestrial gaze on command from the Earth. Later, the photographs were successfully transmitted by radio to the Soviet Union.

This volume contains reproductions of these photographs and describes the methods used in studying them in order to reveal the detail of the lunar surface.

The difficult problems of taking the photographs, processing them, transmitting them, deciphering the recordings, orientating them correctly, and of extracting the information contained therein from the "noise" are fully described and arouse in the reader a sense of admiration and wonder at the ingenuity involved.

Charts are given of the features discovered, with indications of their comparative reliability. In addition, a catalogue of the formations found on the other side of our satellite is included, this catalogue being in three sections of decreasing degrees of reliability. The formations are described in appearance and are interpreted, their coordinates being given in addition.

No doubt this first collection of photographs and information will be augmented by future surveys of the lunar surface, both Russian and American, but in any event, the present volume forms a worthy record of an outstandingly meritorious feat of science and technology.

A. E. Roy.

First Stop: The Moon. By Wolfgang Schroeder, Odhams Press, Ltd., 191 pp., 18s.

Quite early in this book Wolfgang Schroeder comments: "The only obstacle to real space travel which is of consequence, is our lack of an efficient method of propulsion for the spaceship." Few will dispute this, because, given *unlimited* power, all other problems confronting us could undoubtedly be solved, even if somewhat inefficiently.

The author continues to state that there is no indication that such a method is being developed at the moment, or that one is likely to be found in the near future. But, one day, someone will have the "brilliant idea" which will provide the solution, and in the author's mind there is no doubt that this will be a form of atomic-rocket motor converting nuclear energy directly into electricity, instead of heat. This, too, is a technical possibility.

However, "armed" with this as yet undeveloped motor, Mr. Schroeder goes on to devote a great part of his book to a detailed description of what he considers, very strongly, will be the optimum spaceship. And this, to one brought up in the B.I.S. school of thought, as was the reviewer, makes strange reading indeed.

The general practice, Mr. Schroeder explains, of putting the rocket motors at the rear of vehicles, is "perfectly in order as long as the rocket remains in the atmosphere, where stabilizers can keep the rocket on course." In space, however, a "far better" way to obtain stability would be "to build the rocket-motors into the fore part of the vehicle, their jets leading into the open through something like gills."

So the early pioneers were not the only ones to think erroneously that mounting the motor in this fashion gives automatic stability. And what better way to saturate the ship with radio-active exhaust!

To decelerate his spaceship, Mr. Schroeder, considers that the "only possible way to solve this problem is to build two sets of rocket-motors into the ship, one set at each end, one to propel it and the other acting as a brake."

As his spaceship develops, the braking rockets are replaced by "jet" engines "for starting and landing manoeuvres in an atmosphere." To keep these within reasonable limits, the spaceship is designed to take-off horizontally, preferably from a large lake, or from the sea, in the manner of a flying boat, supported on fin-like wings. In addition to these motors there will probably be others, "acting at right-angles to the first two, which would come in useful if the spaceship should happen to fall sideways." Steering rockets (additional to the above!) "are necessary at both the front and the rear of the spaceship."

There are many other equally fanciful suggestions and ideas.

This book then, is not one to be sought after for one's own bookshelf, but is worth borrowing even if only to make one realize how conservative the British Interplanetary Society has become.

M. F. Allward.

Physics and Medicine of the Atmosphere and Space. Edited by Otis O. Benson, Jnr., and Hubertus Strughold.

Towards the end of the International Geophysical Year, it was decided to hold the second International Symposium on Physics and Medicine of the Atmosphere and Space.

As a result, in November 1958, at San Antonio, Texas, forty-two papers were presented to some 800 scientists, physicians and engineers. The authors of these papers were all specialists in their own particular field.

This book is a record of those papers and one would imagine that it could only comprise a series of disjointed articles.

The authors of the book, however, have taken great pains to present the papers in such a manner that one can readily follow the sequences and problems of spaceflight.

The initial papers deal with the environmental hazards that must be considered when spaceflight is envisaged; these range from radiation to the effects of ozone on man and materials.

Next are considered the possible propulsion systems required for putting a space vehicle into orbit and the best ways of ensuring that a launch would be successful.

As one would expect, several papers are devoted to the problems confronting the astronaut. These cover a very wide range and include man's adaptation to altitude, weightlessness, nutrition and other physical aspects that will have to be overcome.

Following on from this are papers dealing with the problems that arise should it be necessary to rescue the astronaut during a launching failure, in flight or on completion of a successful mission.

One of the main objects of spaceflight is to explore other planets, the Moon, Venus and Mars being probably the first planets to be considered. Papers have been written giving the known information on these planets and discussing the possibility of their supporting life of any kind.

The concluding papers give the viewpoint of the engineer and physician with respect to spaceflight. Both are in agreement that whilst many of the problems can be overcome by simulation tests on Earth, the final answers can only be achieved by actual spaceflight.

In the last 2 years, tremendous strides have been made in this field and animals have been put into orbit and successfully retrieved. Thus some of the problems outlined in these papers have been overcome. Whilst it is agreed that the possibility of putting a man into space is imminent, to do so for any prolonged period will still require a vast amount of research. Thus many of the problems as yet remain unanswered and the steps being taken to overcome them are indicated in these papers.

This book should be an asset to those concerned with the problems of spaceflight. In addition, whilst the layman may find a few of the papers a little technical, the overall picture as presented should make this volume a worthwhile addition to his bookshelf.

G. BEARDSHALL.

A Primer of Space Medicine. By M. P. Lansberg, Elsevier Monographs, Elsevier Publishing Co., 15s.

The best feature of this book is its recognition and stressing of the development of space medicine from aviation medicine. Great names of the past (Paul Bert, Tissandier and his ill-fated colleagues) and of the present century are paid due respect; the book is dedicated to Professor J. Jongbloed. The Introduction (first of four parts) leads up to a straightforward statement of the physiological problems of space medicine—particularly those due to progressive loss of atmospheric pressure. Part II deals with environmental problems in manned orbital vehicles and it is perhaps rather uneaven in the amount of attention given to dynamic, *vis-à-vis* climatological factors. A concept of von Braun's of a wheel-shaped satellite revolving continually around the Earth's terminator (surely a difficult state of affairs to maintain?) is used as the peg on which to hang much of the physiological speculation. A meaty chapter on the physiology of the sense organs (specifically, the organs of balance) pays copious tribute to the contribution made by the Dutch school of neurophysiology to research in this field. Part III reviews the forces—acceleration, vibration and noise—which afflict the space traveller during actual flight between Earth and orbit. The topic of re-entry receives a rather cursory mention. The final section of the book summarises some of the outstanding problems of space medicine and comments cautiously on certain aspects of long range interplanetary flight. There is an extensive bibliography which, in common with the rest of the book, is in the main factually reliable although marred by typographical errors.

Although much scholarship has gone into this neatly produced little book, it suffers from two major defects which are singularly unfortunate in a textbook entitled as a "primer". These defects are firstly, unreadability and secondly (despite the assertion made at the beginning of Chapter 9), an excess of speculative digression. It is a difficult book to read, even for those who already have some grounding in aviation physiology. The presentation of material is often inconcise and rambling—particularly in the opening chapter and in the sections dealing with the satellite "microclimate," the physiology of the sense organs and man's acceleration tolerance. Possibly the text has suffered in translation but the style of writing, embodying a curious alternation between turgidity and raciness, is frequently excruciating. Jargon words are used liberally: occasionally the are unashamedly coined. (On p. 149 it is stated in summary: "The break-off' phenomenon is discussed. The term *ecplexia* is suggested for this phenomenon as being more consonant with medical parlance.")

There is in this book much personal theorising by the author which interests but does not instruct: the curious digression at the beginning of Chapter 4, in which it is brought out that specific gravities become zero during weightlessness, is both confused and confusing. It must be conceded that when Dr. Lansberg is indulging in his own personal trains of thought, he is as a rule scrupulously careful to say so. But it seems inappropriate in such a slim and ostensibly elementary volume to devote a third of the otherwise promising introductory chapter to a metaphysical treatise on the clock paradox. By contrast, temperature regulation of the space vehicle microclimate receives a scanty couple of pages, while current developments in practical space medicine (such as the preparations for Project Mercury, which were widely published before 1960) receive no mention at all. It is with hesitation and sadness that one feels compelled to say that a book by so eminent an author in his field cannot be recommended for the purpose for which it was presumably written. It is a revealing monograph but it is not a primer.

J. G. GUIGNARD.

Space Biology. By James S. Hanrachan and David Bushnell, published by Thames & Hudson, pp. 263, 35s.

In their foreword the authors state that the book is not a textbook of space biology but is, instead, a historical survey of the accomplishments from earliest time. In saying this the authors underestimate the value of their book to scientists and engineers working in all fields of space biology.

Basically the book is a concentrated digest of a very wide range of literature relating to the subject but provides easy reading matter punctuated with occasional humour. The 721 references, which include a high proportion of scientific papers, also extend from Greek literature to modern science fiction; from *Pravda* to the *Alamogordo Daily News*; and from the music of Borodin to that of Marty Gold.

Although most of the book is concerned with the achievements of the U.S.A. this is understandable in the light of the relatively small amount of published literature describing work outside that country. The authors have made no attempt to hide the shortcomings of the American efforts and, in fact, one is inclined to wonder whether they have perhaps sought to highlight some of the more amazing follies. Apart from the failures due to obvious lack of attention to detail one realises that much of the apparent lead gained by the Russians in manned space flight is due to the appalling lack of official enthusiasm in the earlier American work.

In the case of a book of this type, where the authors have generally confined themselves to quoting other authorities, little comment is possible on any inaccuracies. In any case it seems apparent that most of the sections have been critically examined by specialists and it is disappointing that there are a number of misleading conclusions drawn in the Section dealing with the atmosphere within the cabin, whereas the sections on weightlessness, G-forces and radiation appear to have been so expertly edited.

The authors' main contribution is their analysis of the impact that space travel is making and could make, on the human race and they make it clear that the scientists and engineers cannot be absolved from blame should their efforts to widen human knowledge have other than beneficial results.

The conclusion reached after reading the book is that the authors are experts in the art of seeking our information and must have direct access to at least one first class reference library. Apart from being presented with a large number of useful facts the interested reader is provided with a means of making a detailed study of any chosen field of the science by making use of the references provided and it is, therefore a book which should appeal to both amateurs and professionals alike.

P. W. FITT.

Correspondence

SIR,—I have been prompted to write this letter due to a howler which appeared on p. 112 of the May, 1961, issue of *Spaceflight*:

"Specific impulse is defined as "lb. thrust" divided by "lb. per sec. mass flow" (F/W = lb./lb./sec.). The lb. units cancel out leaving specific impulse units in seconds".

The writer, having taken pains to differentiate between the units of force and mass, proceeds to cancel the lb.-force with the lb.-mass. The section in which this occurs, entitled "Electrical Rocket Propulsion," also commits the crime of mixing units, quoting thrust in lb.-force and power in kW.

This business of scientific units has been dragged up time and time again, but I still hope that the following contribution to this subject will be valuable. All our troubles may be traced back to Newton's Second Law of Motion, which may be written for a body of fixed mass:

$$F \propto M.A. \quad \therefore \quad F = k.M.A. \qquad \ldots \quad (1)$$

Where F is a force, M is a mass, A an acceleration, and k is a *dimensionless* constant. In any gravitational system of units k is made *numerically* equal to $\frac{1}{g_o}$, where g_o is a standardized value of Earth's surface gravitational acceleration. In this manner the weight of a body *at the Earth's surface* is approximately numerically equal to its mass. This advantage is small consolation for the confusion that has arisen between units of force and mass. This is due to $\frac{1}{k}$ being given the units of acceleration in order to identify it with the system of units being used. Thus we say "in the English gravitational system $\frac{1}{k}$ is equal to 32·17 ft./sec²", instead of $\frac{1}{k}$ has the value 32·17 in the English gravitational system."

Rocket propulsion deals with bodies of variable mass, and so equation (1) becomes:

$$F = k.m.C \qquad \ldots \quad (2)$$

Therefore, specific impulse, $$I = \frac{F}{m} = k.C \qquad \ldots \quad (3)$$

where m is an exhaust mass flow rate and C is an exhaust velocity.

Note that although specific impulse and exhaust velocity may be numerically different, they have the same dimensions:

$$\text{Specific Impulse} = \frac{\text{Force} \times \text{Time}}{\text{Mass}} = \frac{\text{Mass} \times \text{Acceleration} \times \text{Time}}{\text{Mass}} = \text{Velocity}$$

Thus 1 unit of specific impulse =

$$= 1\,\frac{\text{lb.}_f\text{sec.}}{\text{lb}_m} = 1\,\frac{\frac{1}{k}.\text{lb}_m.\frac{\text{ft.}}{\text{sec}^2}.\text{sec.}}{\text{lb}_m}$$

$$= \frac{1}{k}\,\frac{\text{ft.}}{\text{sec.}} = 32{\cdot}17\ \text{ft./sec.}$$

AEROFOIL SECTIONS

F. W. Riegels 1961 282 pages Price £10

In times when slenderness is such a desirable attribute of wings, and supersonic speeds are commonplace, there is a tendency to think of low-speed, two-dimensional flow as an outdated topic. It is forgotten that the subject is still of importance: it is continually required in the design of ship propellers, turbines and compressors; and it is still of use for a wide variety of aircraft.

Dr. Riegels' books provides a clear and comprehensive survey of the subject of wing profiles, surveying all the main theories and discussing many of the experimental investigations. Not the least useful part of the book is the large amount of tabular and graphical information on the geometrical and aerodynamic characteristics of profiles.

NUCLEAR PROPULSION

Edited by **M. W. Thring** 1960 300 pages Price 50s.

In this book experts in their various fields examine the prospects which nuclear power offers in propulsion, particularly in the propulsion of ships, aircraft and rockets. Its basis was a successful course of lectures held for some time past at Sheffield University and its aim is to provide engineers with the basic groundwork of theory, and then to discuss the application of nuclear power to propulsion.

BUTTERWORTHS, 4—5 Bell Yard, London, W.C.2

The confusion can be avoided if we return to equation (1) and put $k = 1$, so eliminating one numerical constant from our equations. An absolute system of units is obtained, so that in the English system the force unit is the poundal and specific impulse is quoted in poundal. sec./pound.

Although we have now purged "g_o" from our equations, we are still left in the English system with a horde of conversion factors, 12, 550, 2240, 5280, 33,000, etc., *ad nauseam*. To cut a long story short, a decimal, absolute system of units is proposed, the metre-kilogram-second (M.K.S.) system.[4] The M.K.S. system only differs fundamentally from the c.g.s. system in electromagnetic theory, but in the mechanics of large-scale phenomena leads to more handleable numbers.

There is no need to explain the metre and the kilogram, but the force unit, the Newton, may be a little strange. From equation (1)

$$\begin{aligned} 1 \text{ Newton (N.)} &= 1 \text{ kg.} \times 1 \text{ m./sec}^2 \\ &= 10^5 \text{ dynes} \\ &= 0{\cdot}2248 \text{ lb.}_f \end{aligned}$$

The Newton (N.) is very convenient for expressing the thrust of electrical propulsion systems (a 10,000 kg. electric rocket requires a thrust of about 10 N. for an acceleration of 10^{-3} m./sec.^{2}), but for chemical and nuclear-thermal rockets it is convenient to use the kilonewton (kN.).

Thus the sea-level thrust of the Rolls-Royce RZ chamber is almost exactly 600 kN. (135,000 lb.$_f$). the Rocketdyne F-1 chamber has a thrust of about 6700 kN. (1,500,000 lb.$_f$), and the Pratt & Whitney LR-115 currently has a thrust of about 67 kN. (15,000 lb.$_f$).

Specific impulse is expressed conveniently in $\frac{\text{kN. sec.}}{\text{kg.}}$ so that:

$$1 \text{ kN.sec./kg.} = 1 \text{ km./sec.} = 101{\cdot}98 \frac{\text{lb}_f\text{.sec.}}{\text{lb}_m\text{.}}$$

Pressures are conveniently expressed in N./cm.^{2}, and stresses in kN/cm^2,:

$$\begin{aligned} 1 \text{ N./cm.}^2 &= 1{\cdot}4504 \text{ p.s.i.} \\ 1 \text{ atmosphere} &= 10{\cdot}13 \text{ N./cm.}^2 = 14{\cdot}69 \text{ p.s.i.} \\ 1 \text{ kN./cm.}^2 &= 1450{\cdot}5 \text{ p.s.i.} = 0{\cdot}6477 \text{ ton}_f\text{./sq. in.} \end{aligned}$$

The M.K.S. system of units may be slightly strange but it is certainly not obscure, for it has been used by U.S. workers in the field of advanced propulsion,[1,2] and extensively by Corliss[3] in his book, "Propulsion Systems for Space Flight."

The experience of a Government Establishment, which adopted the M.K.S. system about a year ago, has been that, after a few weeks of familiarization with strange units of pressure, thrust, etc., it was possible to talk freely in terms of kilograms, Newtons and Newtons per centimetre squared, and it was only necessary to revert occasionally to English units when talking with people outside.

There was marked advantage in working with a system in which all scaling and conversion factors are powers of 10. In evidence of the use and value of the M.K.S. system, a photograph is enclosed of a system of masses, for calibrating a rocket engine thrust rig. Each mass has been designed so that a force of 100 Newtons is exerted in the gravitational field prevailing in Buckinghamshire.

In attempting to avoid confusion between the units of foree and mass, may we not drop the term weight? A search of the literature has revealed no accepted[5] definition of weight, which can take any of the following meanings:—

(1) The weight of a body is the force with which it is attracted towards the Earth.[5,7] Therefore the weight must vary with latitude, longitude and height, and continually decreases as the body moves away from the Earth. Carrying this to the ridiculous extreme, the weight of a body on Mars would depend on the relative positions of Earth and Mars. Note that according to this definition, a body in orbit around the Earth is far from being weightless.

(2) The weight of a body is the reaction force exerted on it upon contact with another body. The weight is now a function of the state of motion of the body. Therefore a man sitting on a chair has weight equal to the force exerted upon him by the chair, but if the latter should collapse, then the man would be momentarily weightless. Note that according to this definition the thrust-to-weight ratio of a vehicle *in vacuo* is always unity, irrespective of its state of motion.

(3) A weight is a body of known mass,[6,7] used to measure the mass of another body by comparison of the forces exerted on these bodies in a uniform gravitational field.

Now we cannot have it both ways. We cannot, for example, say that the weight of a space capsule put into orbit is 1000 kg. and at the same time describe the occupant as being weightless. There is much to be gained and nothing to be lost by dropping the term "weight," and using only the terms force and mass.

It may be argued that the English gravitational system of units and the term "weight" are now so firmly established that the effort required to change would not justify the results. This is pure laziness. If the scientist wishes to have a greater say in human affairs, particularly in astronautics, he must learn to express himself accurately, concisely and with consistency. He cannot do this if he uses a system of units which confuses the concepts of force and mass, leads to expression of physical quantities in nonsensical units, and camouflages his equations with conversion factors and numerical constants.

The B.I.S. can give a positive lead in this matter by indicating to authors of papers a preference for the M.K.S. system of units and by giving greater consideration to terminology and units.

We are on the threshold of the greatest adventure in man's history. It would be a pity if astronautics were to perpetuate an illogical, ugly, confusing system of units.

R. G. CRUDDACE.

NOMENCLATURE

F	force, thrust	m	exhaust mass flow
k	numerical constant	I	specific impulse
M	mass	C	exhaust velocity
A	acceleration		

REFERENCES

1. A. C. Ducati and G. L. Gann, Plasma Propulsion, A.R.S. 1010–59. Presented at the A.R.S. 14th Annual Meeting, Washington D.C., November 16–20, 1959.
2. Harold R. Kaufman, One-Dimensional Analysis of Ion Rockets, N.A.S.A. TN D-261, March, 1960.
3. William R. Corliss, "Propulsion Systems for Space-Flight," McGraw-Hill Book Company, 1960.
4. G. E. M. Jauncey and A. S. Langsdorf, "M. K. S. Units and Dimensions," Macmillan, New York, 1940.
5. — "The International Dictionary of Physics and Electronics," Macmillan, p. 989.
6. L. B. Macurdy, "Standards of mass," *N.B.S. Instruments*. May, 1951, **24**, 5, 530.
7. — "Dictionary of Physics," compiled and edited by H. J. Gray, 1959.

GET YOUR 1962 SPACE DIARY

Includes:—

*ROCKETS

*ARTIFICIAL SATELLITES and their TRACKING

*SPACE PROBES

*MAN IN SPACE

*ASTRONAUTICAL DATA
Careers . . . . facts and figures

*INTERNATIONAL ASTRONAUTICAL FEDERATION

*ASTRONOMICAL DATA
Glossary . . . facts and figures

*SOLAR SYSTEM

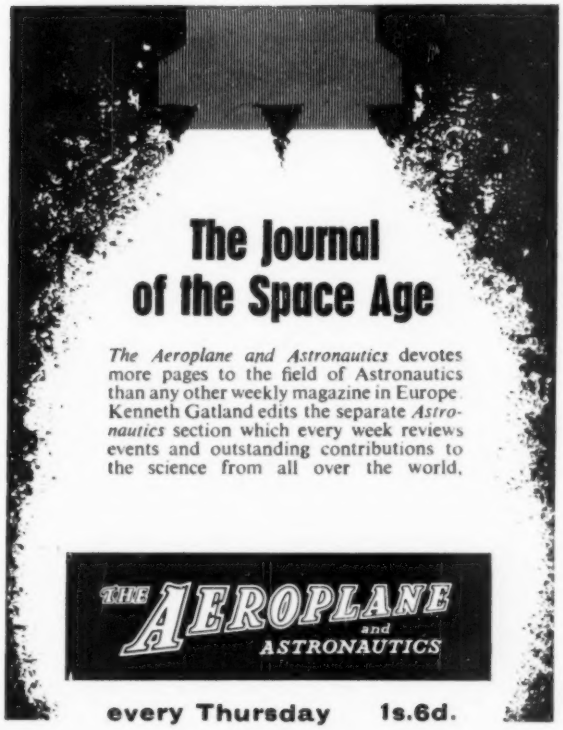
*CONSTELLATIONS

*COMETS and METEORS.

Contained in 64 pages bound in red or blue with gold tooled cover, with pencil in backloop

5/6 post free . . . . U.K.
6/6 ($1.00) ,, ,, ... Abroad

from **INTERPLANETARY PUBLISHING CO.**
12 Bessborough Gardens, London, S.W.1


The Journal of the Space Age
The Aeroplane and Astronautics devotes more pages to the field of Astronautics than any other weekly magazine in Europe. Kenneth Gatland edits the separate Astronautics section which every week reviews events and outstanding contributions to the science from all over the world.
THE AEROPLANE and ASTRONAUTICS
every Thursday 1s.6d.

NEW TITLES

Bio-Assay Techniques for Human Centrifuges and Physiological Effects of Acceleration

Edited by P. BERGERET

Contributed by experts in this field, the papers presented in this AGARD volume discuss various aspects in the study of the human centrifuge and the physiological effects of acceleration. Extensive annotation at the end of each chapter provides further references to study. The book is an essential reference source for surgeons of the air forces, and for doctors dealing with flying personnel in major transport organisations.

Illustrated 70s. *net* ($10.00)

Vistas in Astronomy, Vols. IV and V

Edited by ARTHUR BEER, The Observatories, University of Cambridge

Volumes IV and V continue the highly successful series of volumes which provide a complete survey of contemporary astronomy and its allied sciences.

SOME OF THE REVIEWS OF PRECEDING VOLUMES

"Since the range of topics is extremely wide, there will be few workers in astronomy, in astrophysics, or the physics of the upper atmosphere, who will not each find a few articles to which they will want to refer frequently . . . the Editor has ensured the success of the book by securing many good articles by eminent hands, and the multitude of Professor Stratton's friends will be delighted that this means has been found of honouring him."—Dr. R. v. d. R. Woolley, F.R.S., Astronomer Royal: *The New Scientist*, London.

"Opening *Vistas in Astronomy* at random he (the reader) immediately finds there information both abundant and precise, and often hitherto unpublished; problems neatly posed; and finally, projects for research. He has thus the feeling of participating in the very life of astronomy, and feeling its rhythm. Well-merited success . . . should be regarded as an invitation to produce a sequel."—Professor A. Danjon: *Nature*, London.

Both volumes illustrated *Vol. IV:* 75s. *net* ($12.00)
Vol. V: 84s. *net* ($12.50)

Advanced Propulsion Techniques

Edited by S. S. PENNER, California Institute of Technology

This volume contains the papers and discussions presented at the first meeting of the AGARD Combustion and Propulsion Panel which was primarily concerned with spaceflight.

In this volume are to be found informative discussions of the more promising dynamic advanced propulsion schemes, namely nuclear propulsion, ion propulsion and magneto-fluid dynamic propulsion. However, the application of nuclear propulsion schemes is not necessarily restricted to space missions. The authors of the papers on the nuclear turbojet, ramjet and rockets have clearly stated the formidable cooling, shielding and material problems that must be overcome in order to bring these efforts to a successful conclusion. The far-reaching mission implications of working engines using ion propulsion are also discussed.

Illustrated 70s. *net* ($10.00)

Escape and Survival: Clinical and Biological Problems in Aero-Space Medicine

Edited by P. BERGERET

This book reflects the activity of the Aerospace Medical Panel of AGARD in the last two years by presenting twelve "collected papers" which deal with the practical problems encountered in current aero-space medicine. These include such subjects as escape from aircraft at high altitudes, high speeds and low altitudes, and concepts in Arctic survival training.

Illustrated 45s. *net* ($6.50)

Table and Schematic Chart of Selected Lunar Objects

S. M. KOZIK

The main purpose of compiling this table is to contribute to the improvement of accessories for observing the moon, to increase the accuracy of their mathematical treatment and to help the compilation of a standard list of observable objects which would ensure the comparability of observations made by different persons with different instruments. 12s. 6*d. net* ($2.00)

All books gladly sent on 14 days' approval

PERGAMON PRESS
OXFORD LONDON NEW YORK PARIS
Headington Hill Hall, Oxford
4 and 5 Fitzroy Square, London, W.1
122 East 55th Street, New York, 22, N.Y.

Printed by W. Heffer and Sons Ltd., Cambridge, and Published by The British Interplanetary Society, 12, Bessborough Gardens, London, S.W.1.
Advertisement enquiries to: Cheiron Press Ltd., 3, Cork Street, London W.1. (REGent 5301).

CHARLES FRANK

4 inch NEWTONIAN REFLECTING TELESCOPE

WE WILL BE PLEASED TO SUBMIT ANY ITEM ON APPROVAL

Complete with tripod and ready for use .. £32

An equatorially mounted telescope of great precision and fine appearance. New Features include: Precision Helical focusing eyepiece mount. High quality Kellner ½ in. ocular. Mounted Starfinder.

7 x 50 Richest Field PRISMATIC TELESCOPE

Tripod mounted. Estimated value £120 **£9.0.0**

EX-GOVT. 6 x 30 TAYLOR HOBSON BINOCULARS

Wonderful value. With web case .. **£7.15.0**

Send for illustrated catalogue

EX-U.S. NAVAL 7 x 50 BINOCULARS (Coated)

Current cost approx. £70. Perfect condition with case .. **£24.0.0**

EX-M.O.S. 1/5th SECOND STOP WATCHES

Cost approx. £7. Offered in perfect condition **55/-**

CHARLES FRANK LTD.

67-75, SALTMARKET GLASGOW, C.1

Phone: BELL 2106/7 Established 1907

Actual makers of Astronomical Telescopes and Specialized Optical Equipment.

Nelson's Atlas of the UNIVERSE

by

Br ERNST *and* Tj E. DE VRIES

***edited by* H. E. BUTLER MA PhD**

preface by

H. A. BRÜCK DPhil. PhD

Astronomer Royal for Scotland

An up-to-date guide to space and the stars. The first part of the book consists of over 200 photographs with long informative captions, a brief history of astronomical studies, and an ever broadening view of the Universe. The second part describes in alphabetical order all aspects of astronomy and related topics from Ptolemy to artificial satellites.

94 plates, over 200 charts and diagrams in the text. $10\frac{3}{8}$" x $7\frac{1}{2}$" 42s

NELSON

THE BRITISH INTERPLANETARY SOCIETY

BENEVOLENT FUND

The Society's Benevolent Fund has been established as a means of alleviating distress caused to members or their dependents by disablement or bereavement, etc. Initially, any member of the Society of more than five years' standing (or his or her dependents) is eligible for assistance. Benefits from the fund are NOT restricted to members in the United Kingdom or British Commonwealth.

The Fund is administered by Trustees, who would be grateful if cases meriting consideration could be brought to their attention.

The initial target for the fund is £3,000, the sum received to date £1,201. Further contributions will be welcome. Remittances should be made payable to the B.I.S. Benevolent Fund, and should be sent to:

The Secretary,

12 Bessborough Gardens, London, S.W.1

FOR YOUR TRAVEL ARRANGEMENTS BY SEA, LAND AND AIR CONSULT

NTA

Northern Transport Agency (London) Ltd., 47/48, Duke St., London, S.W.1.

Telephone WHI. 4346

AIR TRAVEL

AIR FREIGHT

AIR CHARTERS

SHIPPING & RAIL ETC.